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# THE CHANGING PHYSICAL ENVIRONMENT OF THE HOPI INDIANS OF ARIZONA

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# ABSTRACT

THE Hopi country lies on the southern escarpment of Black Mesa, a dissected highland about 60 miles in diameter underlain by resistant Upper Cretaceous sandstone. This mesa is drained by the southwestward-flowing, ephemeral streams of the Tusayan Washes, which separate the fingering prongs of the escarpment and thence flow into the barren plains leading to the Little Colorado River. These streams bring sand and silt from Black Mesa to the lower plains where the prevailing southwest winds separate them and carry the sand back northward to bank it against the escarpments of that part of Black Mesa which is the Hopi country. Because of the relatively large quantities of dune sand resulting from this process, the Hopi country has a lower runoff after rain and more permanent springs than areas of similar climate nearby.

The population of the Hopi country numbers about 3000, mostly Hopi Indians, the western remnant of the larger Pueblo group who once occupied most of the southwest. These people are farmers who live in permanent houses built of stone and clustered in villages, located on the high southern spurs of Black Mesa near the springs. The villages are central to the fields on nearby mesa tops and in the broad valleys of the Tusayan Washes.

The Hopi country is too dry for growing crops by rainfall alone, so that special methods of farming are used. The Hopi raise corn and beans, the staple foods, by four different methods. Flood-water farming, in which fields are planted where the floods of streams spread in thin sheets of water, is the most important type. There are two major types of flood-water fields, those located at the "akchins" or arroyo mouths of small streams, and those located on the flood plains of large streams. Sand dune fields, in which the relatively high-moisture content of sandy soils is utilized, are also an important type of field. This type is not affected by epicycles of erosion and dissection of flood plains, as are the flood-water fields. The necessity for the protection of plants from moving sand requires the use of windbreaks, however, and makes this system of farming laborious. Some fields are watered by seepage. A small proportion in which rare and relatively valuable crops are grown are irrigated from springs. Flood-water fields are found in large areas around the Hopi country, but not in as great numbers. Higher regions than the Hopi country are too cold for growing corn. Lower regions are too dry except where fields are located along large water courses which have their sources in wetter regions.

The effect of a period of arroyo cutting in the Hopi country is to shift the position of flood-water fields from the main streams to the akchins or arroyo mouths of small streams and to increase the use of sand dune fields.

The large areas of sand dunes can be used as a means of deciphering climatic change in the recent past. The dune forms of this region are divided into three major types: 1) transverse dunes (including barchans), which are always free of vegetation and are aligned at right angles to the prevailing wind, 2) parabolic dunes, formed in the presence of specialized vegetation, consisting of irregular bow-shaped ridges with their tails or tips pointing into the wind, and 3) longitudinal dunes, long narrow ridges of sand extending across country for miles, and formed in the presence of specialized vegetation. These longitudinal dunes depend on a relatively small quantity of moving sand, derived from a restricted source, which in most places is a groove of deflation in an ancient sand cover. For this reason they can form only where the vegetative cover is relatively unaggressive. Ancient stabilized longitudinal dunes are found in other vegetative zones where nowadays over 15 inches of precipitation fall. Inasmuch as active dunes of this type occur only where there is less than 10 inches of precipitation, it is obvious that at the time of formation of most of the longitudinal dunes the climate was considerably drier than it now is. Stratigraphic evidence indicates a dry period between 2000 and 5000 B.C., during which time most of the fixed dunes now mantling the region formed.

The valleys of the Hopi country and adjacent areas are filled with deep alluvium, now dissected by deep channels or arroyos cut since 1880. The alluvium is exposed in their walls and is obviously divisible into three formations: the Jeddito formation, containing Elephant bones, and presumably deposited before 5000 B.C.; the intermediate Tsegi formation, containing evidence of human

occupation; and the Naha formation, deposited since 1300 A.D. The deposition of these formations alternated with periods of erosion like the present, which were relatively dry. In the Jeddito-Tsegi period of erosion, the great system of dunes now mostly stabilized was formed.

Evidence of ancient farming occurs on the north side of the Jeddito Valley. Many areas of networks of stone lines used to support brush windbreaks are the remains of ancient sand dune fields. One of these is known to be as old as the thirteenth century A.D. Estimates of land available for flood-water farming in the past show it was relatively great in the first millennium A.D., was reduced at the end of the thirteenth century and increased somewhat from 1300 to 1600 or 1700 A.D. Population changes in the Jeddito Valley region may be related to widespread climatic changes and changes in areas available for farming. In any case, the history of the Pueblo people has been greatly affected by the changing physical environment.

The Hopi country is superior as a location for agricultural settlement to other nearby areas. The abundant dune sand provides a better ground-water supply, and inhibits arroyo cutting. The wide valleys provide large areas over which flood-waters can spread.

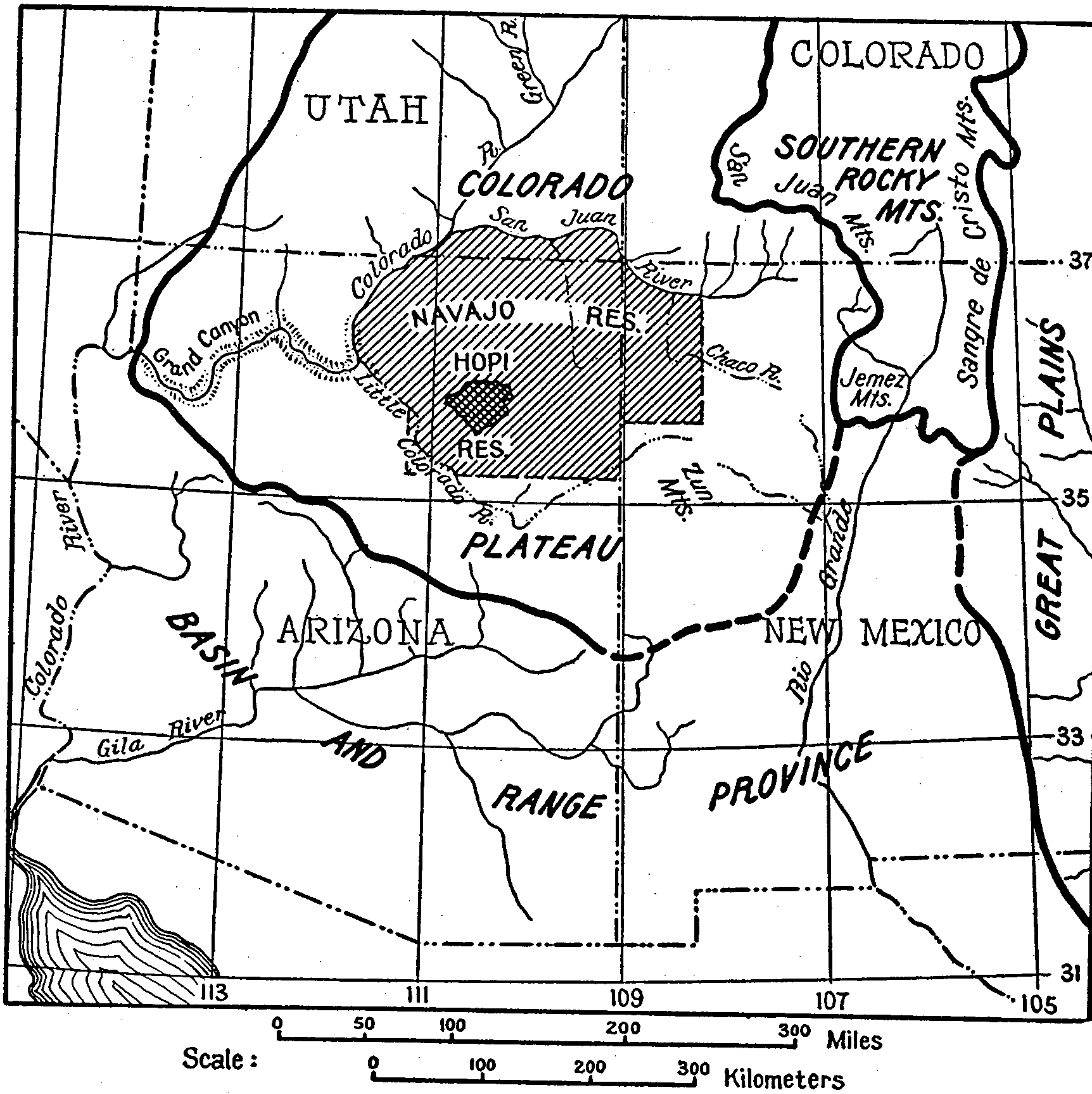


Fig. 1. Index map of the Southwest, showing the location of the Navaho and Hopi Indian Reservations.

# CHAPTER I

# THE MODERN ENVIRONMENT

## PHYSIOGRAPHY

### GENERAL SETTING

THE Hopi country lies in the Navaho section of the Colorado Plateau province. This province is a land of gently folded sedimentary rocks eroded on a majestic scale into broad plateaus, precipitous mesas and buttes, and dark canyons. Over the whole region, the huge swells and gentle folds of the rock strata control the topography, for plateaus, mesa surfaces and rock benches rest on resistant layers of sedimentary rock.

In the western Navaho country a broad structural basin extends from the Little Colorado River on the south and west to the Defiance Plateau on the east, and the Utah line on the north. This is known as the Tusayan downwarp. It is a gently downfolded basin, which is truncated by erosion, and its hard and soft beds are etched into the sharp pattern of relief now visible. The center of this basin thus contains the youngest rocks, the Mesaverde sandstone, which crop out on and support the high, dissected plateau of Black Mesa. Outward in all directions from this mesa, older and older rocks crop out, and their circular plan gives the topography a roughly circular aspect, like a great onion slice centering in Black Mesa.

This topography is shown diagrammatically in fig. 2. The highest point of the region is the north end of Black Mesa, where the resistant Mesaverde sandstone of Cretaceous age forms high cliffs rising above the plains to the north, cut on softer and older rocks. The Tsegi Mesas rest on the Jurassic Navaho sandstone, which is here raised to a height above the surrounding region in a broad fold. Elsewhere the Navaho sandstone underlies mesas of lower altitude, like the Kaibito and Moenkopi Plateau, and the Garces Mesas. The Defiance Plateau rests on the Permian Coconino sandstone, which is truncated by the present land surface at the eastern end of the Tusayan downwarp. The Hopi Buttes are underlain by the resistant lava flows and basalt plugs of the Bidahochi formation, of Pliocene age.

The geology and physiography of the region have been described by several writers. Gregory[1] has written several full and lucid accounts which discuss the geography as well as the geology. A brief description of the geologic formations found in the region around the Hopi country is given below, taken mostly from Gregory,[2] also from Baker and Reeside,[3] and Baker, Dane, and Reeside.[4] This summary description is intended merely as an aid to the memory, for these rock names are frequently referred to in the following pages. For a clear understanding of the bed rock geology the reader is referred to the original sources.

### ROCK FORMATIONS

Permian:

Moenkopi formation—300–500 feet. Chocolate red and banded arenaceous shales and thin sandstones, and rare limestones; extremely variable in stratification; gypsiferous; fossil plants. Underlies a large part of the Little Colorado Valley.

De Chelly sandstone member of the Coconino sandstone—0–585 feet. Light red, uniform-grained, cross bedded sandstone, cliff-maker. Forms large part of the Defiance Plateau.

Triassic:

Shinarump conglomerate—20–100 feet. Cross bedded lenticular conglomerate and sandstone, pebbles chiefly quartz, quartzite, and petrified wood.

Chinle formation—1,182 feet. Red and variegated shales with thin sandstone and limestone conglomerate; gypsiferous and calcareous. Forms badland topography. Crops out in Painted Desert, southern portion of the Hopi Buttes, Chinle Valley, and Tsegi Canyon.

Jurassic:

Wingate sandstone—30–450 feet. Bright red sandstone, massive and cross bedded, fine grained.

[1] Gregory, 1915a, 1916, 1917.
[2] Gregory, 1917.
[3] Baker and Reeside, 1929.
[4] Baker, Dane and Reeside, 1936.

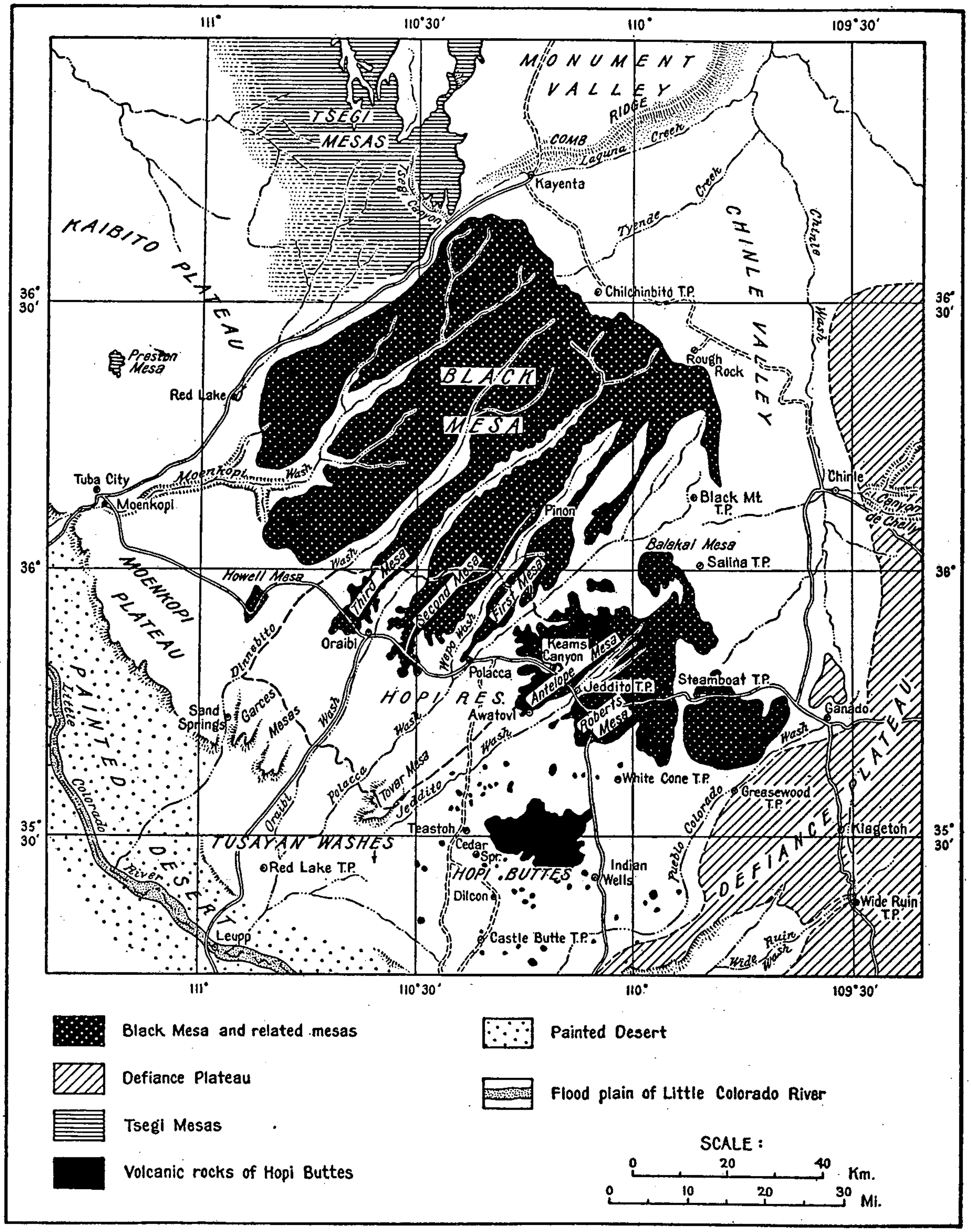


FIG. 2. Physiographic diagram of a portion of the western Navaho country, including the Hopi Indian reservation.

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Crops out in canyons of Tsegi Mesas, and the Chinle Valley.

Kayenta formation—0–200 ft. Limestone and calcareous and arenaceous shales, dinosaur footprints. Crops out in Tsegi Mesas.

Navaho sandstone—400–1,000 ft. Light red, massive, cross-bedded, uniformly fine-grained sandstone, with variable amounts of lenticular limestone, near top; prominent cliff maker. Crops out widely in the region, in the Hopi Buttes, Garces Mesas, Moenkopi Plateau, Kaibito Plateau, Tsegi Mesas, and Chinle Valley.

Morrison formation—400–700 ft. Green, white, gray, and brightly banded sandstone and shale, with beds of gypsum. Crops out in southern part of Hopi country, and all around the western, northern, and eastern rims of Black Mesa.

Upper Cretaceous:

Dakota sandstone—0–295 ft. Gray and brown coarse sandstones, with lenses of arenaceous and agillaceous shale and coal; stratification very irregular, conglomerate in places. Forms cliffs. Crops out in circular belt, mostly very narrow, around Black Mesa. This belt widens near Steamboat Canyon.

Mancos shale—500–800 ft. drab, argillaceous and arenaceous shales with lenses of impure limestone and coal. This formation underlies the broad valleys of the Hopi country, and crops out on the lower slopes of the border of Black Mesa.

Mesaverde formation—275–800 feet. Buff sandstone, massive at base and top; sandstones with arenaceous and argillaceous shale and workable coal beds in central portion; forms cliffs. Crops out on Black Mesa and forms the cliffs on which the Hopi towns are built as well as the ruins of Antelope Mesa.

Pliocene:

Bidahochi formation—0–400 feet. White, calcareous sandstone and limestone, green, pink, and red tuffaceous clay, white tuff, basaltic tuff, and interbedded basalt flows. Overlies unconformably the Mesozoic rocks from the Hopi Buttes to the Defiance Plateau, and extends north to Antelope Mesa. (This formation is not named by Gregory. It has been called the Hopi lake beds by Williams,[6] and is described by the writer in a forthcoming paper.)

[6] Williams, 1936.

### Hopi Country

The Hopi country lies on the southern edge of Black Mesa (see fig. 2) where its southwestward projecting prongs end and give place to the low plateaus of the Tusayan Washes area. Thus the northern portion is a group of high plateaus, called Antelope, First, Second, and Third Mesas, separated by broad, steep-walled valleys, through which the great ephemeral streams flow. Many of the minor streams radiate outward from the mesa sides and from the bases of the mesa points. Some of these never reach the main watercourses, but fan out on the broad valley flats.

The southern portion of the Hopi country is comparatively flat. The high buttressed mesas which divide the streams in the northern portion are there replaced only by low divides, or plateaus, and the valley flats make up most of the area.

The Tusayan Washes which pass through the Hopi country rise high on Black Mesa in narrow canyons and carry out to the flats to the southwest great quantities of débris of all sizes. In the intervals between the ephemeral floods some of this débris is carried upstream by the prevailing southwest winds, and the constant contest between water and wind work results in the accumulation of enormous quantities of sand in the Hopi country and in the area of the Tusayan Washes.

To the east, the Hopi Buttes cut off the wind, and what little sand is blown in this region is quickly carried away by water. This is also true of the narrow winding canyons of Black Mesa. On the Moenkopi and Kaibito Plateaus, the wind has an open sweep and has covered the country with a thin veneer of sand, but there are no streams traversing the plateau surfaces, and thus no great supply of sand is available for transport by the wind.

The Hopi country then, differs from the areas around it in having enormous quantities of windblown sand in its valleys and piled up on its mesa sides, and yet has many drainage lines consisting of ephemeral streams which spread out over a relatively large proportion of the valley floors.

## CLIMATE AND VEGETATION

### General Relationships

Southwestern United States is arid because moisture, either as rain or snow, is small. The lack of rain results from the inland position of the area far from the Atlantic Ocean and Gulf of

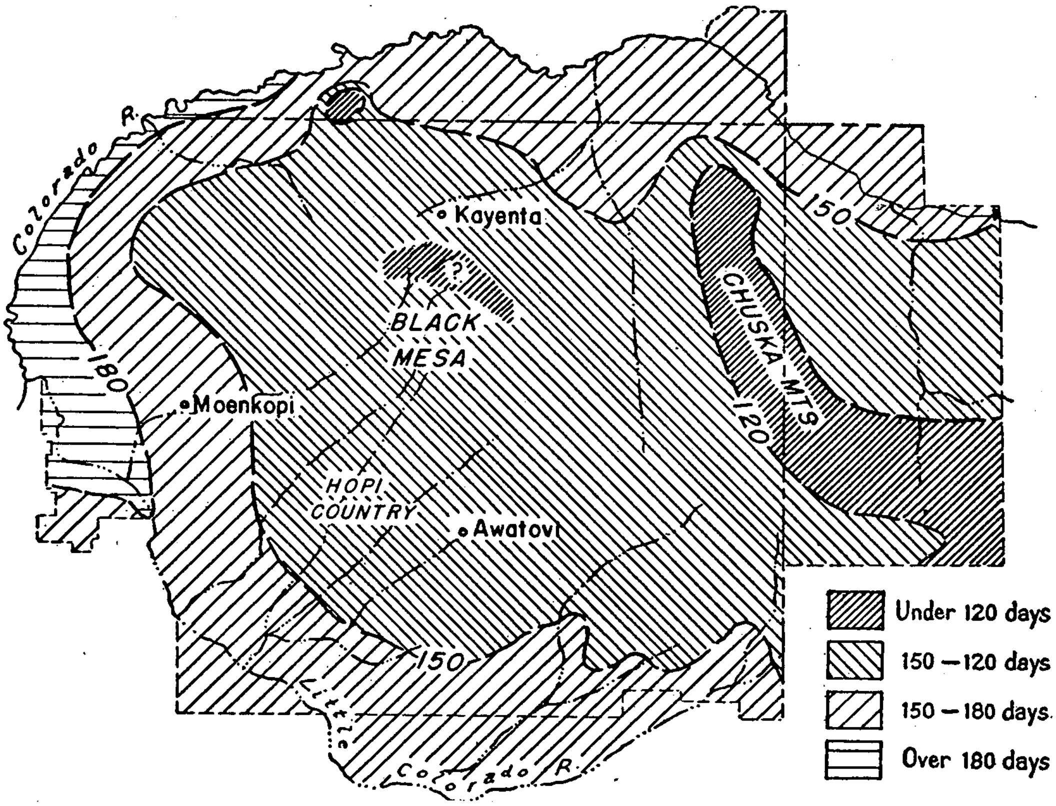


FIG. 4. Map of the Navaho country, showing the average length of the growing season (modified from a map in the *Atlas of American Agriculture*).

length of the growing season is indicated in fig. 4, however, a map modified from a map in the *Atlas of American Agriculture*, prepared by Read, Brooks and Marschner.[7]

Thus in the Navaho country the regions with the longest growing season are very dry, and the moist regions have a very short growing season. Crops are most successfully grown in regions between the two extremes where the mean annual precipitation is about 12 inches, and the length of the growing season about 130 days. This relationship is discussed more fully in Chapter III.

### General Characteristics of the Climate of the Hopi Country

The rainfall varies from about 10 inches in the lower portions of the Hopi country to about 13 inches in the higher portions. The mean annual temperature is around 51 degrees.

The seasonal variations in climate are very marked. Each of the four seasons has a distinct type of weather. Through all the seasons, however, two characteristics of the climate remain the same. The first of these is the small amount of cloudiness and the abundance of clear weather. The second is the daily march of temperature which varies little from month to month in amount, and varies on the average from night to day about 30 degrees. Although this daily temperature change may be as much as 60 degrees and occasionally as low as 10 degrees, the temperature varies usually with such regularity that one can predict on a clear day in the morning just what the temperature will be at each hour of the day. The annual march of temperature follows closely the altitude of the sun, the temperature being the highest in July and lowest in January. The regularity of the temperature and the dominance of solar climate is shown clearly in fig. 5 where the average maximum and minimum temperatures have been plotted for Keams Canyon.

[7] Read, 1918.

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Precipitation has a marked seasonal distribution. The wet seasons are winter and summer, and the dry seasons, fall and spring. In the winter, precipitation falls mostly as snow. The maximum snowfall occurs in January and from then until May the precipitation gradually decreases. In May and June the humidity is very low, and rain rarely falls. These two months are characterized by strong winds, causing sandstorms and duststorms which make this season the most unpleasant of the year. This dry windy season is also a factor in making agriculture precarious, for the plants are often killed by the sand cutting the young tender shoots. Protection from sand is necessary for some of the crops.

The summer rainy season usually begins suddenly about the middle of July. About 3 or 4 inches of rain falls on the average during July and August, This rain usually falls not in general storms in which the sky is completely overcast as in the eastern United States but as scattered thundershowers, some of great violence. For periods of several days or even weeks, in the summer, the weather may be entirely clear, but then will begin a rainy period of several days duration. During this rainy period, the nights are usually clear and cool although rain occasionally falls at night. Clouds form in the middle of the morning and grow in size moving slowly up over the region usually from the southwest. In the afternoon large thunderheads grow, scattered over the region. Rain falls from these as they move across the country drenching everything in their path. Sometimes when the air is less humid, the clouds are so high that if rain falls it may dry up before reaching the ground. Rarely "general rains occur" when for periods of several days the whole region may be clouded over; then the temperature both at night and during the day is cool and rain falls intermittently in light showers or drizzles. Even during these storms the sky is apt to be clear during the night, and the distribution of rainfall is very irregular from place to place.

Great storms may also occur which are similar to the usual thundershowers but are more violent, and cover larger areas. A rainstorm in which over one inch of rain has fallen in a few hours was observed at least once every summer at Jeddito in the four years preceding 1939. One storm, in 1938, which the writer observed was a violent thunderstorm, occurring in the middle of an August afternoon in which over one and one quarter inches of rain fell in less than an hour's time. It is this type of storm which is active in cutting and filling arroyos, and which is valuable in providing water for crops.

In September the rainy season ends not suddenly but by a gradual lengthening of the intervals between storms. Fall weather is the most pleasant in the Hopi country, being comfortably cool, dry and sunny. Strong winds are rare in this season.

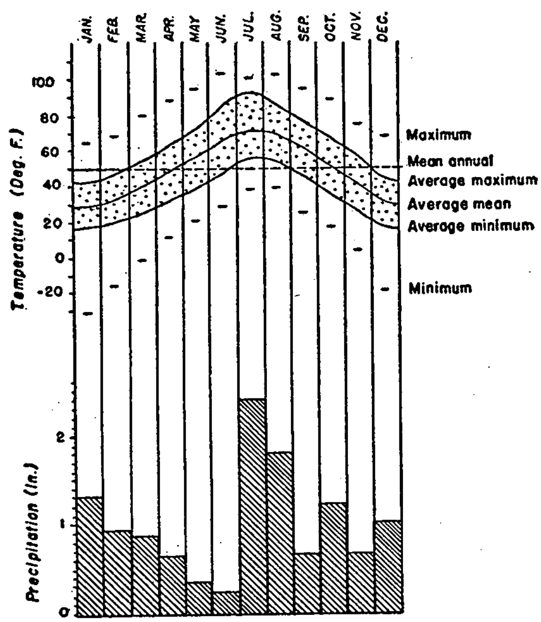


FIG. 5. Mean monthly precipitation and temperature at Keams Canyon.

The wind direction in the region is strikingly uniform during the whole year, coming predominantly from the southwest. The summer thundershowers move up slope from the southwest, and the sand-moving winds of spring strike the landscape from the southwest. The abundant ancient and modern dunes of the region have a parallelism suggesting constant scouring from this southwesterly direction. However, other winds are of frequent, but intermittent occurrence, and sand-moving winds from other directions occur.

### VEGETATION OF THE HOPI COUNTRY

The mesa surfaces of the Hopi country are woodlands consisting of scattered juniper and piñon trees with interspersed stands of sage brush. The valleys and low plateaus, however, lie below the climatic zone in which these plants can grow and there only grasses and desert shrubs cover the land. The dominant grasses are blue grama grass and drop seed, a bunch grass. The dominant shrubs are mormon tea, greasewood, shadscale, salt bush, snakeweed, and rabbit brush. Sage brush is common also but is confined to the mesa surfaces.[8] There are many areas of waste land, of bare washed slopes and active sand dunes.

Physiographic conditions which determine soil types have a strong influence on the vegetation, especially in the lower areas. Areas covered by fixed dunes, for instance, make better forage than areas of clay or adobe soils, for they usually support more grass.

A survey made by David W. Dresbach of the U. S. Soil Conservation Service[9] divides the land of the Hopi Reservation into the following areas.

| Forage types | Acres | Percent area |
|---|---|---|
| Grassland | 169,634 | 33.98 |
| Browse | 257,862 | 51.66 |
| Sagebrush | 3,527 | .71 |
| Piñon and juniper | 38,465 | 7.70 |
| Waste | 19,356 | 3.87 |
| Cultivated | 10,404 | 2.08 |
| | 499,248 | 100.00 |

## WATER SUPPLY

### General Statement

In a region as dry as the Hopi country water supply is probably the most important environmental factor determining the concentration of population. Water is needed not only for drinking but also for watering crops, for the rainfall alone is not sufficient for successful crop production. Water for crops is obtained mostly from surface runoff, and between floods is held in porous soils. Some water, however, derived by underground circulation is utilized by crops. Drinking water is obtained mostly from springs and shallow wells, though a small amount is obtained from rock tanks which are filled by surface runoff.

The water supply of the whole Navaho country has been discussed in detail by Gregory.[10] More information can be added, however, and an account of the occurrence in the Hopi country itself with particular regard to the favorability of the region is important.

[8] See p. 81 for scientific names of plants.
[9] U. S. Soil Conservation Service, 1937.
[10] Gregory, 1916.
[11] Grover, 1939.

### Surface Water Supply

All of the streams of the Hopi country and surrounding regions except a portion of the Jeddito Wash, are ephemeral, and flow only after heavy rains. The Tusayan Washes, which consist of the Jeddito, Polacca, Wepo, Oraibi, and Dinnebito Washes, are the master streams of the region. These are long and important streams which rise high on Black Mesa. The Dinnebito and Oraibi Washes reach the Little Colorado River 100 miles to the southwest. The others drain to the Oraibi Wash or to one of its tributaries. At the present time these washes all have deep arroyo channels. The Oraibi is probably the largest, being 80 feet deep and several hundred feet wide, near the village of Oraibi. All of these washes are in some places cut to bed rock, but in most places they are both floored and walled with alluvium. In the stretches where the alluvium is shallow they may contain small trickles of water even in dry weather. This perennial water is usually alkaline but suitable for stock. The Jeddito Wash in its lower course has a small perennial flow for a distance of several miles.

No records of flood discharge on the Tusayan Washes are available. There is a gauge on the Moenkopi Wash, however, which records an average discharge of about 10 second feet. On August 4, 1929, during a flood, this gauge recorded a discharge of 15,100 second feet, almost equal to the average discharge (17,790 second feet) of the Colorado River at Lees Ferry.[11] Thus these relatively short ephemeral streams at times carry floods of water equal in size to the average flow of one of the largest streams in the United States.

Once runoff reaches one of the streams of the Tusayan Washes it is in most cases lost for use by the inhabitants, for it is carried to the Little Colorado River in deep channels. But flood irrigation is practiced along the lower Jeddito Wash, for it fans out before reaching the Little Colorado. The government is at present constructing a flood irrigation project near the confluence of the Oraibi and Polacca Washes which will utilize these large streams.

Minor streams are numerous in the Hopi country, but are lacking in large areas on low plateaus where thin but widespread deposits of dune sand prevent runoff almost completely. In areas free of dune sand there are many water courses. Most of them flow in arroyo channels but fan out onto the surface and deposit the detrital loads carried during floods before they reach the main channels of the Tusayan Washes. Their flood waters are thus available for flood irrigation.

Before 1900 the main streams did not flow in arroyo channels but their stream beds were so shallow that during large floods they frequently spread over their banks. The epicycle of erosion which has occurred over the whole Southwest since 1880 began somewhat later in this area. These main washes as well as some of their tributaries are now incised. Many of these tributaries, however, as yet remain unaffected by this process and still spread over their banks during floods.

At present the government has dammed many of the smaller minor streams in order to provide reservoirs to store water for stock. This supply rarely lasts through a whole year, being available only a few months after the rainy season. The prehistoric inhabitants apparently did not make use of this water supply for no remains of ancient reservoirs have ever been found in the Hopi country.

The Hopi make use of rock tanks or cisterns however. These consist of naturally or artificially enlarged holes in bare rock surfaces to which extend runnels carved out of the rock, that act as collecting channels. The rock tanks provide a water supply of easy access to the inhabitants of the Hopi towns.

### Ground Water

The principal supply of water for drinking is now obtained from springs or from deep wells drilled by the U. S. Government during the last forty years. Wells are used principally to supply water for stock, and the Hopi still obtain most of their drinking water from springs or shallow dug wells.

The principal supply is derived from springs. By far the most important type is the mesa spring (fig. 6-1). Antelope, First, Second, and Third Mesas are underlain by the Mesaverde sandstone. Throughout this region the highest layer is usually a massive sandstone 10–30 feet thick, which is underlain by impervious clay or shale. Water is stored in the massive sandstone and issues as springs at various points on the mesa edges where joints concentrate the flow. Elsewhere at this horizon plants commonly grow in profusion, utilizing the water which seeps out. All the large

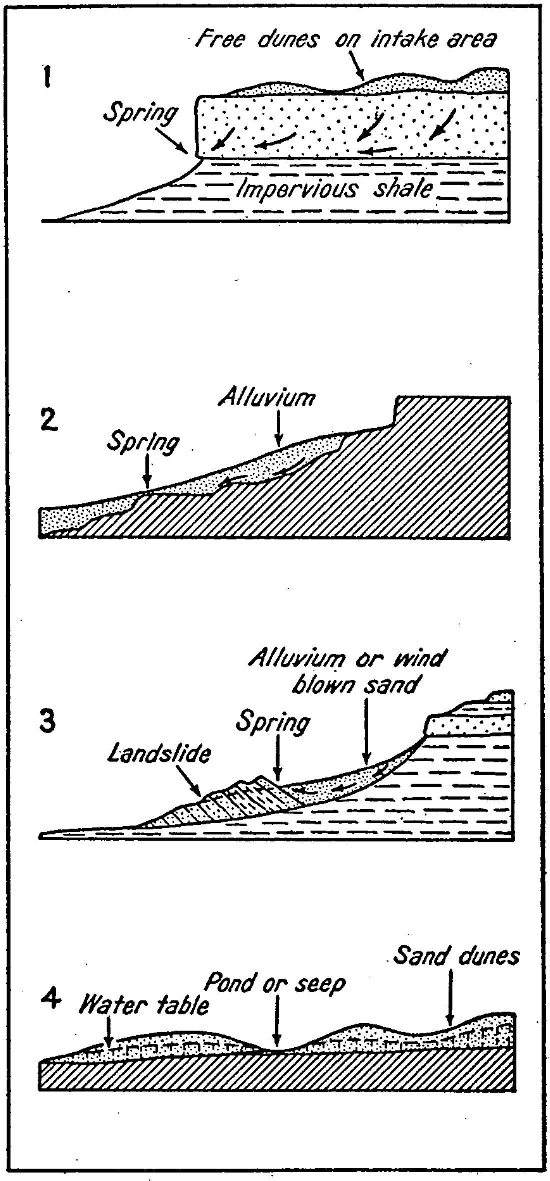


Fig. 6. Types of springs common in the Hopi country: 1, Mesa spring; 2, contact spring; 3, landslide spring; 4, seep in dune hollow.

springs such as Tallahogan spring, Canelva, Wepo, etc. which are used for irrigation are mesa springs. They are further discussed on page 36.

Much of the drinking water in the Hopi country is obtained from contact springs of the type illustrated in fig. 6-2. Sand dunes and alluvium are in many places banked up against the impervious Mancos shale or shale of the Mesaverde

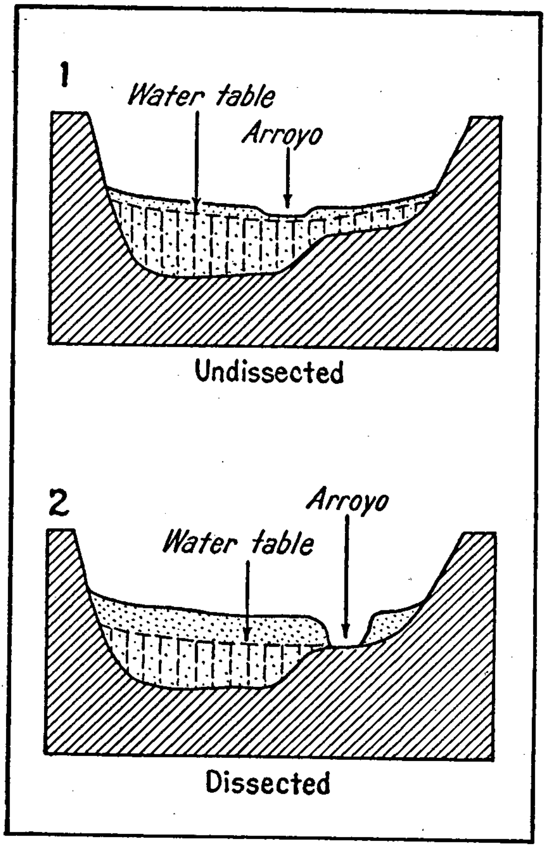


FIG. 7. The effect of incision of streams on the ground water table in a valley filled with alluvium. In no. 1 the stream channel or arroyo is shallow, and the water table is high. In no. 2, the arroyo bottom is on bed rock, and the water table is considerably lower, its level being determined by the depth of the arroyo.

sandstone. Whenever a layer of impervious rock is near the surface under one of these sand banks, water may be obtained by digging or may emerge as a spring. The spring just east of Awatovi is of this type, as is the spring at Jeddito Trading Post.

Contact springs in alluvium are common where great landslide blocks, called Toreva blocks by Reiche,[12] have slid off the mesa edges and dunes of alluvium have partially covered them. These blocks have fallen off the mesa on a sort of parabolic curve so that the strata are turned up away from the mesa, and hence dip toward the mesa at high angles (see fig. 6-3). Many of these landslides or Toreva blocks are dissected by deep arroyos which during a cycle of filling, have filled with detritus, much of which is very coarse. The Toreva block acts as a dam, holding the water in the alluvium in back of it, and the water is concentrated in the filled arroyo channels. This type of water supply is illustrated by Spider Spring, near Hano, or by Lemeva spring near Mishongnovi, both important springs. A detailed map of Spider Spring is shown in fig. 16, page 30.

A minor amount of water is obtained from hollows in dunes which in wet seasons may contain ponds of water. In some of these hollows the ground water table may be tapped by digging a shallow well. This water supply is best developed where free dunes cover an impervious bed rock. Examples are found in the area of free dunes on First Mesa.

The alluvium which covers the valley floors of the Hopi country contains important supplies of ground water. Much of the alluvium is porous and in many places rests on impervious shale which holds up the interstitial water. At the present time this important reservoir of water is tapped by government wells and pumped out by windmills for the use of live stock. In addition many of the arroyos of the Hopi country are incised in the alluvium deeply enough to tap its water supply. Before the present epicycle of erosion began, the water table under the large ephemeral streams was probably high, and water could have been obtained in many places by simply digging a shallow well. This process of lowering the water table by the incision of streams is illustrated in fig. 7.

### IMPORTANCE OF DUNE SAND TO THE WATER SUPPLY

There is no doubt that the Hopi country has a better water supply than any other region on the edges of Black Mesa. This has been accounted for by the statement that the dip of the Mesaverde sandstone, a good aquifer, is to the southwest, and therefore Black Mesa serves as a collecting basin for the springs emerging at the southwest edges of the mesas in the Hopi country.[13] This explanation is geologically impossible. Black Mesa occupies an elliptical structural basin whose axis is approximately an east-west line running a short distance north of the Hopi towns. Thus in the area occupied by the Hopi the dip is not to the south at all. Measurement of the basal member of the Mesaverde sandstone, with a Paulin altimeter, at various points in a triangle between

[12] Reiche, 1937.
[13] Forde, 1931.

Jeddito, Shungopovi, and Piñon shows that the average strike of the rocks is north 70 degrees east. The dip in the region of the Hopi mesas, is about 50 feet to the mile to the northwest. This accounts for the fact that the strongest springs in the Hopi country are located as a rule on the northwest mesa sides.

Furthermore, there are seeps along the bases of the aquifers all over Black Mesa. There is little possibility of ground water moving very far in any direction. The intake areas of all of the springs of the Hopi country are small and are to be measured in tens or hundreds of acres, not square miles.

The most important reason for the abundant supply of ground water is the existence of excellent intake areas. The Hopi towns are located on barren, rocky, mesa spurs. On broad mesa flats, nearby, a thick dune cover has been blown up over the mesa edges. Bare sandstone with no soil or vegetation on it makes a fairly good collecting area. It is improved by a cover of dunes which greatly impede runoff, and especially by free dunes with no cover of vegetation.

It has been shown in many parts of the world that plants may use up large supplies of ground water. Water is taken into the roots of plants from the ground, and evaporated from the leaves, during the growing season. This physiological discharge of water is called transpiration. In humid regions, the effects of transpiration are rarely important, because the recharge of the groundwater by rainfall is relatively great, but in arid and semi-arid regions, the effects are very important.

Elaborate studies by White[14] in the Escalante Valley, Utah, on transpiration by plants similar to those of the Hopi country (including rabbit brush, the most common plant of the dune areas) show that in regions of shallow ground water the discharge of ground water by evaporation and transpiration about equals the average annual recharge from precipitation. Studies of dunes in Gascony, by Edouard and Jacques Harlé[15] show that planting of trees and shrubs for the purpose of fixing dunes, resulted in a marked lowering of the water table. Teakle[16] noted that in the agricultural areas of western Australia, clearing of land resulted in many cases in permanent streams breaking out where only ephemeral streams had previously existed. Many studies showing such effects of transpiration have been made. Transpiration is undoubtedly a very important factor affecting the discharge of springs as well as the flow of streams in the Navaho country. Gregory[17] points out the importance of transpiration and evaporation, and shows that the exceptionally good springs of the Tuba district are largely due to the dune covered areas of their large collecting basin, where there is little runoff and a porous aquifer beneath the dunes.[18]

Transpiration is especially important in the Navaho and Hopi country, because well over half of the annual precipitation occurs during the growing season, and a large part of the remainder falls as snow, which is more liable to be lost by evaporation. The dune areas which are free of vegetation thus offer excellent intake areas for ground water. Dunes prevent runoff and most of the water, protected from evaporation by the loose sand can seep into the porous rock below and issue from a spring on the mesa side. The importance of dunes is shown by the map, fig. 8. which shows the large areas of irrigated gardens. These are all fed by mesa springs (fig. 6-1), Tallahogan spring is located just below a large area of active dunes, free of vegetation. Canelva and Wepo springs are near the large active dunes on First Mesa. There are no large areas of dunes on Second Mesa and no large irrigated gardens. At Hotevilla on Third Mesa, there are irrigated gardens, above which is a large area of parabolic dunes which has been cleared for planting peaches, beans, and corn. These furnish a good in-take area. Other large springs are commonest along the points of the narrow mesa prongs where the wind keeps the vegetation from growing too thickly.

At Jeddito Trading Post there is a contact spring of type 2 (fig. 6) which until 1939 supplied the home of the trader, Mr. Roberts, as well as a sheep dipping vat, with abundant water. When Mr. Roberts came to Jeddito in 1920 there was a large flowing spring. Since then he has planted about 100 trees in the drainage area of the spring, and in 1936, he fenced in the area allowing grasses and shrubs to grow, undisturbed by sheep. Sacaton, a ground water feeder, is the most abundant plant in this fenced area. In April, 1939, he noticed that the spring was low. In September, 1939, after a severe drought the water

[14] White, 1932.
[15] Harlé, 1920.
[16] Teakle, 1939, p. 5.
[17] Gregory, 1916, p. 129.
[18] Gregory, 1916, p. 146.

was insufficient even to supply the Trading Post. The rainfall in 1937 and 1938 was about normal. In this case a large spring has apparently become nearly dry because of the growth of vegetation.

Thus the importance of a thick sand cover, free of vegetation, to present a large collecting area is shown to be of great importance to the water supply. Without the sand much of the water would run off the mesa top on the less porous rock surfaces or the thin soil. Other areas of Black Mesa are less fortunate. Protection from the wind enables thick juniper forests to grow and consume large supplies of water. It may be that where there are now high dunes, overgrown with vegetation, near the mesa edges, it might pay to remove the vegetation by plowing or harrowing and thus increase the flow of seeps or springs below.

The surface of Antelope Mesa, not now occupied by the Hopi, is covered with thick sand, and the mesa edges are in many places buried by it, but the springs, except at Tallahogan Canyon, are not very large. When the region was thickly settled in pre-Spanish times it is probable that agricultural activity of the Indians kept the portions of the mesas near the towns free of vegetation, and that springs were then as plentiful on the rim of Antelope Mesa as they now are on First and Third Mesas. The modern springs are thus no measure of the water supply of the past.

FIG. 8. Map of the Hopi country, showing principal villages, ruins, springs, roads, and large areas of active dunes. Note the relationship between the large springs and irrigated gardens, and the areas of active dunes.

part of the nineteenth century. Toreva is really not a Hopi town but contains a school and mission. The remaining six towns are all built on the ends of the projecting spurs of Black Mesa, and have all been founded since 1680.[5] The inhabitants before that time lived in villages below the mesa tops and apparently moved up on top after the Pueblo rebellion, perhaps in fear of the Spaniards. Hano is a village of Tewa Indians, whose ancestors moved over from the Rio Grande region at this same time or shortly thereafter.[6]

The Hopi are village dwellers, who are accustomed to change their ways, or their place of abode more slowly than their neighbors, the Navaho. Their homes are permanent structures, built of sandstone, with wood and mud roofs. The location of their dwellings is largely determined by their agricultural economy and by the water supply. The largest springs of the whole region are located near the mesa ends on the south side of Black Mesa, where the large quantities of sand on the mesa tops make good intake areas for the springs below.

Agriculture and especially flood irrigation leads to central locations for dwellings. The Hopi farms are located in the valleys and on the mesa sides, in every bit of land suitable for farming. Although fields are in many places far apart and some of the largest of them are on the most distant borders of the Hopi Reservation, centrally located permanent dwellings are desirable, for the position of fields change, and several fields are usually cultivated by the same family. Small farmhouses, near fields far from the central towns, are commonly occupied by individual families during small parts of the year.

## EARLY HISTORY OF THE HOPI AND THE PEOPLE OF THE JEDDITO VALLEY

The history of the Hopi before the arrival of the Spaniards is known only from archaeological research. Other reports of the Peabody Museum Awatovi series will deal with this subject in detail. Agricultural peoples ancestral to the modern Hopi have occupied the region at least since Basketmaker III time (500–700 A.D.) and probably earlier. Ruins of villages and houses closely resembling those of the Hopi are found all over northeastern Arizona, and it is certain that the Hopi are the cultural descendants of a people who once occupied a much larger area. The cultures of the San Juan and Little Colorado areas are the most closely related.

The excavations of the Peabody Museum Awatovi Expedition were carried on in the Jeddito Valley region which lies on the eastern border of the Hopi Reservation. In addition to many small ruins, ruins of four large and several medium sized villages, which were occupied from about 1100 to 1500 or 1700 A.D., are found on the north side of the valley.

The Jeddito Valley ruins are so similar in construction to the modern towns and their environment is so similar, that although the valley is now occupied by Navahos it should geographically be considered a part of the Hopi country. One Hopi (Sequi) still lives near Jeddito Trading Post. He is a member of the Warrior Clan, and considers himself the guardian of the Hopis' right to the land of the region. His wife is a Navaho.

The history of the Hopi is undoubtedly affected by the relatively recent intrusion of the Navaho. It is not known how important this effect is or when it began to develop. It may be that the Navaho were an unimportant tribe in the Southwest until they obtained horses from the Spaniards. There is no evidence of the time of their arrival or of their importance in prehistoric time. They are first mentioned by Fray Alonzo Benavides, O. F. M., in his Memorial to the King of Spain written in 1630.[7]

## CONCLUSION

Hopi economy except for recently introduced activities is primarily agricultural. Before the coming of the white man they must have depended entirely on their own resources for food, clothing and shelter.

Because of their dependence on agriculture, which is certainly practiced under great difficulties in this dry region, the Hopi are very much affected by changes in their environment, and the suitability of a region for habitation depends entirely on conditions of climate and physiography.

[5] Colton and Baxter, 1932.
[6] See Colton and Baxter, 1932, for other details.
[7] Franciscan Fathers, 1910.

## Chapter III

# THE PHYSICAL BASIS FOR HOPI AGRICULTURE

SEVERAL studies of primitive farming have been made which in a general way point to the conclusions presented here. Gregory[1] describes briefly the most important type of Hopi and Navaho farming, flood irrigation or flood-water farming. Bryan[2] made a more detailed study of flood-water farming and gave examples of its variations as practiced by Pueblos and Spaniards. Studies of the agriculture of the Hopis have been made by Hoover,[3] Clarke[3a] and Forde,[4] the last with emphasis on the sociological problems connected with farming. The reader is referred to these sources for other aspects of Hopi farming.

The present study deals only with the physiographic aspects of farming. Owing to lack of rainfall to produce either good soil or enough water for farming as the Anglo-American practices it, the prime problem of the Hopi farmer is that of watering his crops. The fields may thus be classified on the basis of their water supply which, in turn, depends largely on the physiographic position of the field.

The success of the present study is in large part due to the excellent maps and agronomy surveys of the U. S. Soil Conservation Service. Much data obtained by this bureau was generously loaned to the writer and is used freely in the following pages.

## CROPS

The principal food of the Hopi is corn. This is used in many different ways. It is ground into meal and made into bread, mush, or the delicacy, *piki*. It is eaten on the cob, or made into hominy and used in stew. Fruit crops are also important. They may be dried or stored for a long time like corn. They are principally peaches, melons, apricots, and apples. In addition a few grapes are grown. Beans, which are grown in abundance, are also an important crop. There are a few irrigated gardens in which small crops of onions, tomatoes, squash, cabbages, carrots, tobacco, chili, corn, apples, peaches, and other plants are grown. These crops, though of small amount, are probably of importance in Hopi diet and ritual. The table below shows the percentage of total farmland devoted to the production of these various plants.

Percent of Total Area of Farmland Devoted to Various Crops

| Crop | Percent |
|---|---|
| Corn | 72.0 |
| Peaches | 8.9 |
| Apples | 1.5 |
| Apricots | 2.8 |
| Melons | 2.6 |
| Beans | 8.7 |
| Garden | .1 |
| Idle | 2.8 |

Some of the plants now grown, notably peaches, and many garden plants have been introduced since Spanish time.[5] In considering the crops of ancient farmers, cotton must be considered as one of the important plants, even though it is not grown in large quantity today. At the time of the coming of the Spaniards it was probably next to corn in importance, and apparently was planted in the same kind of fields.[6]

## RELATION OF AGRICULTURE TO CLIMATE

### Problems of Climate

As was shown in Chapter I, the Hopi country has a rainfall of only 10 to 13 inches. Spring is the driest time of the year, and is characterized by strong, sand-moving winds. The growing season is about 130 days, a period short enough to permit considerable damage from frost.

These difficulties are met by the use of crop plants specially adapted to the region, by special crop practices and by the location of fields in physiographic positions which permit the concentration and conservation of water.

### Special Plants

Hopi corn is a variety well adapted to the

[1] Gregory, 1916, p. 103.
[2] Bryan, 1929b.
[3] Hoover, 1930.
[3a] Clarke, 1928.
[4] Forde, 1931.
[5] Whiting, 1939.
[6] Jones, 1936.

severity of the climate. It is planted about 10 to 15 inches in the ground to a depth at which moisture is held in the sandy soil. Ordinary corn cannot be planted deeper than 3 to 5 inches. When full grown, Hopi corn reaches a height of only 3 or 4 feet except in exceptional cases.[7] This deep planting allows the plant to gain moisture during the dry spring and helps protect it from very late frosts. Some moisture is stored in the subsoil in the proper locations throughout the dry spring.

In prehistoric time the Hopi made their clothing from cotton, which they raised in the Hopi country.[8] The growing of cotton has now ceased almost entirely except for a small amount for ceremonial purposes, but at one time cotton was grown in flood-water fields in the same position as corn. It is a special variety known as *Gossypium hopii*, which can apparently be grown far outside the normal range of other varieties.

Other crop plants as far as known are similar to varieties grown in other parts of the world. Many varieties of the adaptable bean are found in the Hopi country. Several plants such as peaches, apples, carrots, onions, have been introduced by Europeans, and thrive under the farming practices of the Hopi.

## The Problem of Frost

The growing season in the Hopi country has a length of about 130 days. This period might be adequate in wetter regions but in the Hopi country crops are often lost because of damage by frost. This is partly because the water supply is scanty and the crop matures slowly. An unusually long spring drought may require a new planting during the summer, with increased danger of frost damage in the fall. The Hopi usually begin planting corn about the 15th of April.[9] Only a small amount is planted at this time. It is intended to be harvested at the end of July and roasted while still green for use in a festival known as the *Nimankatcina*. The writer has observed that many of the fields in which early corn is grown are located in narrow gullies on steep slopes where the nocturnal radiation of heat from the gully walls protects the plants from frost. About the first of May some watermelon and squash are planted. But the main planting of corn does not take place until the middle of May or about the time of the last killing frost. It lasts until the summer solstice (June 21). Each family will have certain planting dates set aside which cover the whole of this planting period. This spread in planting dates may provide for the loss of early corn due to a late frost in June when the crop may be replanted, or for the loss of late corn due to an early frost in the fall.

The harvesting of the corn planted in April takes place at the end of July, a period of about 100 days from the time of planting. This corn is still green and is roasted as part of the *Nimankatcina* festival. The main harvest begins about the 25th of September, 130 days after the beginning of the main planting. By this time a frost has often already occurred.

The dates of planting and the growing season for a twenty-two year period averaged from the records at Keams Canyon and Jeddito are indicated diagrammatically in fig. 9. The planting dates used are those given by Forde[10] and apply only to First and Second Mesa, whereas the climatic records are taken from points about 15 miles to the east. Planting dates at Third Mesa, in the western portion of the Hopi country may be somewhat different. The diagram is only a rough indicator of the relation of the planting dates to the frost-free season, but it clearly shows that the growing season available is little longer than the season necessary to ripen corn and be assured of good crops.

## Rainfall

A mean annual precipitation of only 11 or 12 inches such as characterizes the Hopi country is not sufficient to grow corn without special methods. Flood-water farming is necessary and is the dominant type of agriculture in the region. Small rains, such as are of frequent occurrence, may not even wet the ground and it probably takes a rain of .20 or .30 inch to cause an arroyo to run. It is only these rains which are of value for crop production.

Because the rainfall of each day nearly always occurs in a single storm of short duration, it is possible to use the daily rainfall records as a measure of the amounts of rain which fall in single storms. The analysis of rainfall concentration can be shown in several ways. One of the most obvious is shown in fig. 10. Here are shown

[7] Collins, 1914.
[8] Jones, 1936.
[9] Forde, 1931.
[10] Forde, 1931.

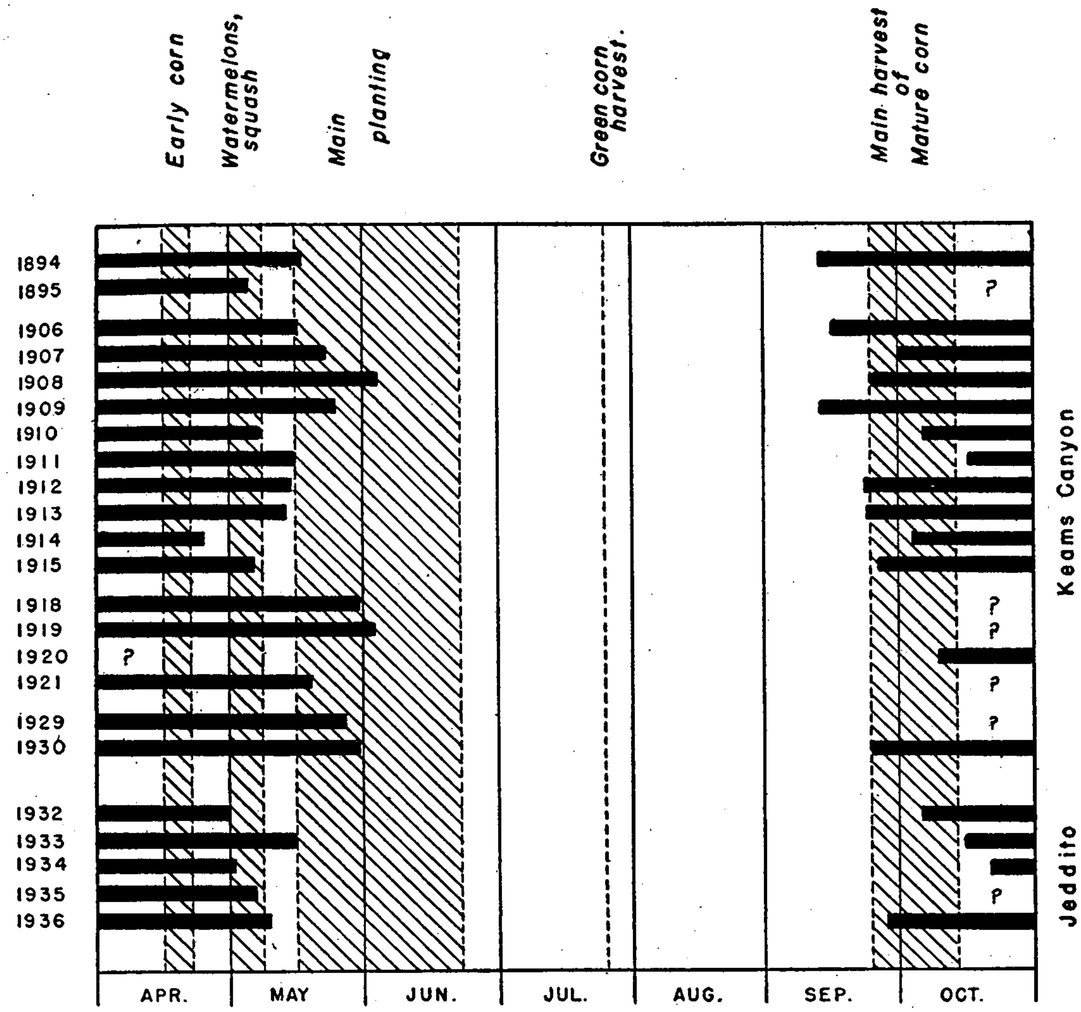


FIG. 9. Relation of planting dates at First Mesa (after Forde, 1931) to the length of the frost-free season at Jeddito and Keams Canyon. The black bars represent periods during which frost occurs. Shaded areas are times of planting and harvest.

the number of days each year on which rain of different amounts fell at Jeddito in the period 1935–1937. There were only four days when more than 1 inch of rain fell and they were all in the summer. On the other hand more light rains occur in winter than in summer. In summer probably only thirty days out of this 3-year interval have had sufficient rain to cause arroyos to run and thus to water the fields. This is an average of ten days a summer. The yearly means from a three year record at Jeddito and a ten year record at Kayenta, of the total amount of rain which falls in storms of over .30 inch during each month are shown in fig. 11. The totals are a measure of the moisture effective for the watering of fields and available each month. This diagram also shows that this effective rainfall is most concentrated in the summer months. Note that there is twice as much effective rainfall at Jeddito as there is at Kayenta.

But flood-water farming does not depend on the absolute amount of precipitation available. It depends on location so that a sufficient frequency of floods occurs. Thus a field might be located in a region where the frequency of heavy rains is very low, but might receive water from a drainage area where the frequency of heavy rains is very high. Most of the fields in the Hopi country

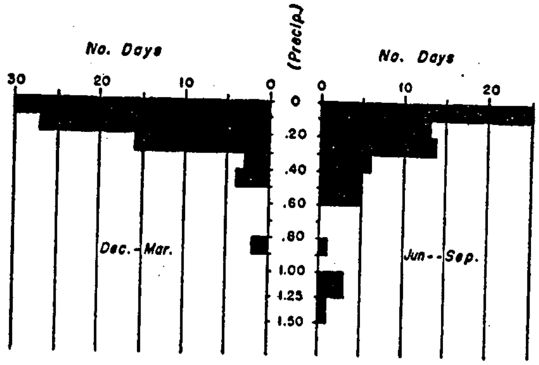


FIG. 10. Diagram showing the sizes of storms in which rain has fallen in the winter and summer seasons, for a period of three years, at Jeddito Trading Post. Each bar represents the number of days on which precipitation of the amount shown in the vertical column has occurred. Note that large rains are not frequent, and are more common in the summer than in the winter.

are now located on very short arroyos, but there are many areas of fields in the Navaho country which are in dry regions or even in desert regions and have a distant source of flood-waters in more humid areas.

## Climatic Zones and Agricultural Zones

One of the reasons why the Hopi country is now inhabited by an agricultural people is because it lies in the local climatic zone which is most suitable for agriculture. It was shown on page 7 that in the Navaho country, which surrounds the smaller Hopi country, the mean precipitation increases with altitude and the length of the growing season decreases with altitude. It is obvious that in regions with very low precipitation agriculture can hardly be practiced at all, and in regions of the highest rainfall, the growing season is too short. The Hopi country lies in the zone which has 10 to 12 inches of precipitation, which, as shown by fig. 3, is the favorite zone for farming. Dense farming areas outside of this zone are located either along very large streams like the Little Colorado River, or where springs are abundant as along the Echo Cliffs. Thus the Navaho country can be divided into zones of agriculture, related to zones of climate.

The Chuska Mountains and portions of the Defiance Plateau rise above the elevation at which the growing season is generally shorter than 120 days. Much of the area of Black Mesa which rises to an elevation of 7,500 feet or more probably has a growing season shorter than that suitable for corn. The length of the growing season is thus a factor limiting the type of agriculture practiced by the Navaho and Hopi Indians. In this connection it might be argued that the corn grows more rapidly in regions of higher precipitation. Although this may be true to some extent, the critical period in the growth of the plant is the

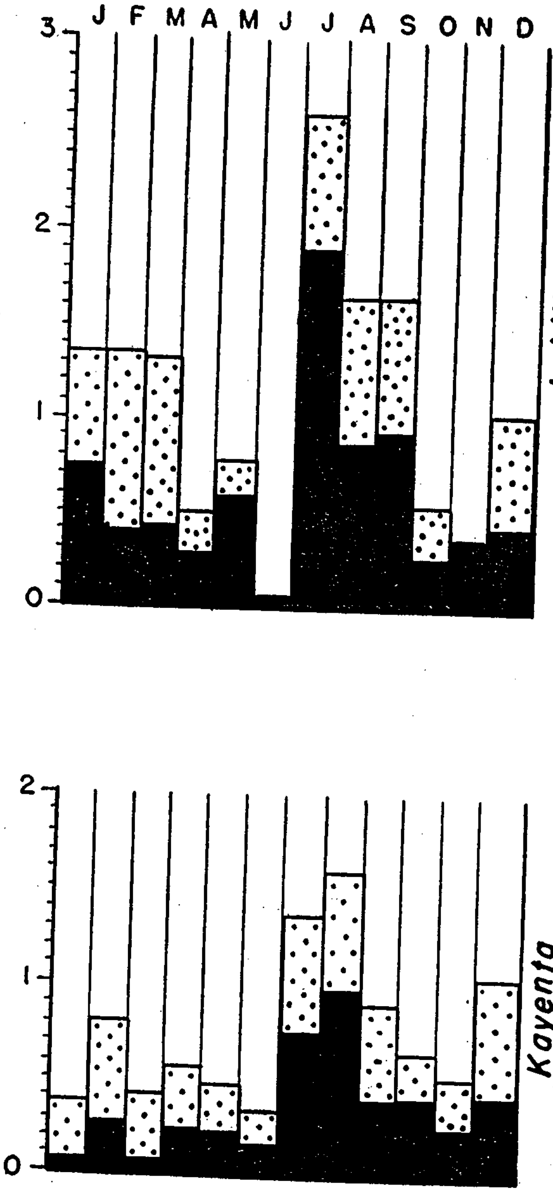


FIG. 11. Average monthly precipitation at Jeddito (3 year period) and Kayenta (10 year period). The black bars represent the average amount of precipitation which falls in storms of over .30 inches.

June dry season. All the stations have a very low precipitation in this month and the average annual frequency of June rain is only one day greater at Flagstaff, the wettest station, than at Keams Canyon.

Thus there must be a zone in the Navaho country in the highest areas, and in the areas of greatest precipitation, in which corn cannot be grown. The lower limit of this zone is probably defined by the 16 or 18 inch rainfall isohyet. Below this isohyet, the growing season is long enough for the growing of corn, although the zone at which corn crops are relatively safe from frost must be considerably below the 16 inch isohyet. Throughout the lower areas, free from danger of frost, the agriculture is limited by lack of rainfall or by the small frequency of rains of sufficient magnitude to flood the fields.

Flood-water farming is practiced throughout the Navaho country, but in the areas with the highest rainfall, the fields are located on smaller arroyos than they are in the areas with lower rainfall. In the driest regions only the largest water courses, like the Little Colorado River, or the Chinle Wash, which head in areas of great rain frequency will support agriculture. Thus in the 10–12 inch rainfall zone (fig. 3) the fields are scattered over the country, between the main water courses, as in the Hopi country. Lower down in the drier regions, the fields, which are few, cluster along the main water courses. The Tuba City area appears to be anomalous. Fields in this very dry region are irrigated by permanent streams or by springs which appear in the Moenkopi Canyon, and along the base of Echo Cliffs.

Thus the farming in the Navaho country may theoretically be divided into four zones which depend entirely on climate.

1) Zone of no corn production and scant farms in which precipitation is over 16–18 inches, and the growing season is shorter than 110 to 120 days.

2) Zone of precarious flood-water farming in which precipitation is over 12 inches and less than 16 to 18 inches, and the growing season is longer than 120 days.

3) Main zone of flood-water farming (on small arroyos) in which precipitation is over 9 to 10 inches and less than 12 to 13 inches, and the growing season is adequate.

4) Lower zone of flood-water farming in desert regions (on main water courses), in which the rainfall is less than 9 inches, and the growing season is adequate. Farming in this zone is precarious because of the difficulty of protecting fields from powerful floods.

This theory of zonal distribution of agricultural practices is derived primarily from analysis of the climate. However it may be checked by consideration of the map in fig. 12 which shows the location of fields of the principal crops. This map is a reduction of the agronomic maps made by the U. S. Soil Conservation Service in their census of 1937. Three administrative districts extending from the northeast end of Black Mesa (Elev. 7,500 feet) to the Little Colorado River (Elev. about 4,150 feet at Leupp) are included. The maps include the entire drainage areas of the two largest Tusayan Washes, the Polacca and the Oraibi. District 5 is the driest of the three districts and is occupied by Navaho Indians (Pop. 1,212–1.0 per square mile). District 6 is occupied mostly by Hopis (Pop. 2,779–3.6 per square mile), and District 4 on Black Mesa is inhabited almost entirely by Navahos (Pop. 2,422–1.6 per square mile).

At the headwaters of the Tusayan Washes there are few fields, and the crops are principally oats, potatoes and alfalfa. No corn is grown in the fields having the highest altitudes. This is the climatic zone in which corn cannot be grown because of the short growing season. Further down toward Piñon, the number of fields increases, and corn, beans, and melons, which are the principal crops of both Hopi and Navaho predominate. In this region the main streams are entrenched in the alluvium of the narrow canyons of Black Mesa and fields are planted mostly on the floors of small tributary canyons at the ends of short gullies or water courses.

In District 6 the fields are relatively dense. Here they are located mostly at the ends of shallow arroyos of somewhat greater length than those utilized in the area to the north. The much greater concentration of fields in this region is of course due in part to the fact that its population has an agricultural economy whereas the inhabitants of District 4 are primarily stock raisers. However this reasoning may be reversed. The Hopi, as the first comers, undoubtedly chose to inhabit District 6 because it is a more favorable place for agriculture than Districts 4 or 5.

In District 5 there are almost no fields. According to the theory of agricultural zones, and according to Gregory's map (see fig. 3) there should be fields scattered along the course of the

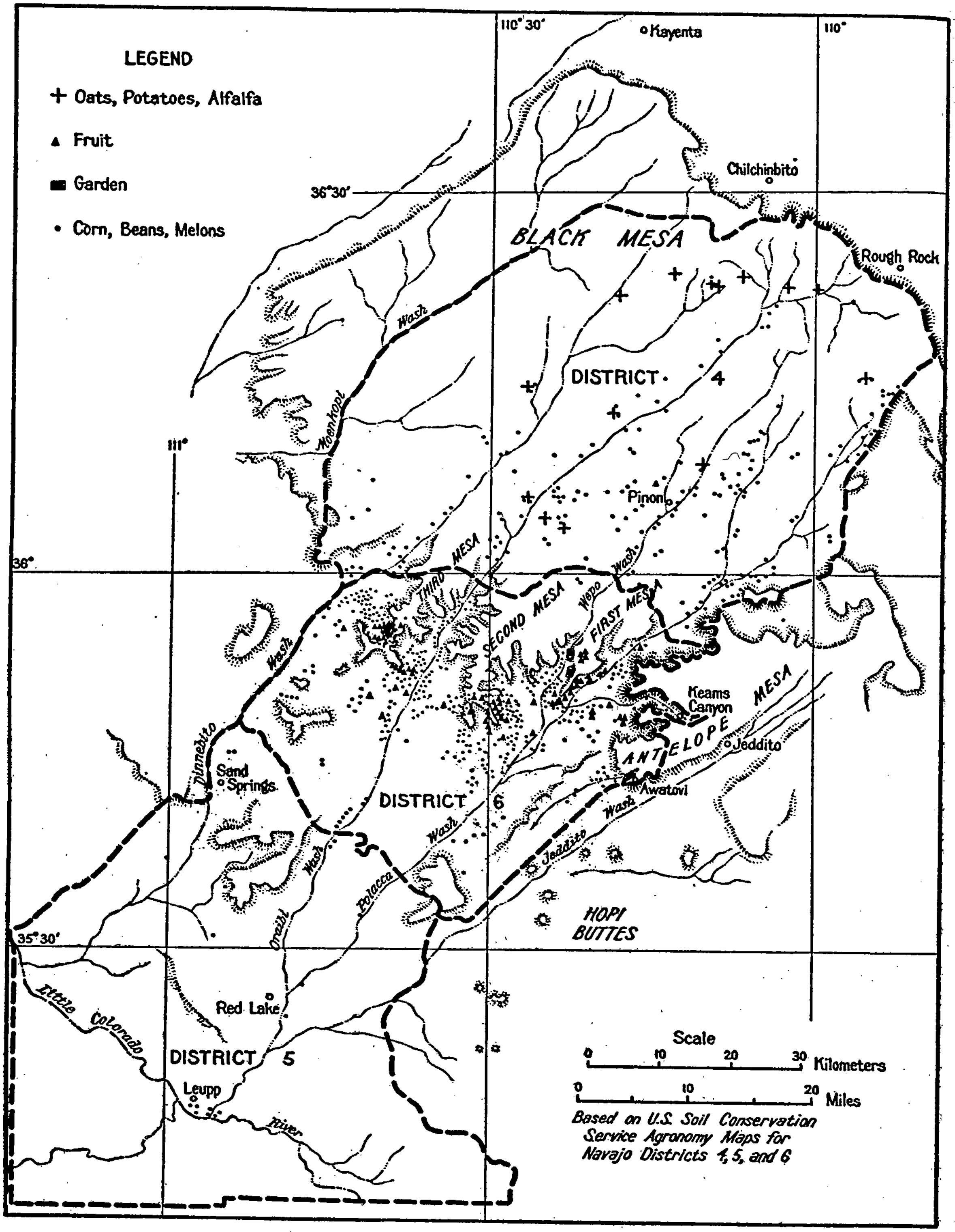


FIG. 12. Map of the drainage basins of the TusayanWashes, including Navaho Land Management Units 4, 5 and 6. Shows the zoning of agricultural crops from low, warm and dry areas (along the Little Colorado River), to high cold and wet areas, where crops which mature quickly are most common.

Little Colorado River. Most of the fields in this district are located near Leupp in a government planned irrigation project. Mr. J. W. Bush of Dilkon Trading Post informed the writer that at one time fields were located along the Little Colorado, but were unsatisfactory because of frequent destruction by large floods. Colton[11] has shown that in 1880 the stream bed of the Little Colorado River was much narrower than it is now, and contained a well-regulated perennial stream. Cottonwood grew in abundance on its banks, and pools and stream were inhabited by beavers.

The map of the agriculture in these three districts (fig. 12) bears out the idea of zoning of agriculture in the Navaho country. The Hopi country is in the most favorable zone where the growing season is adequate, and where the rainfall is sufficient to permit the location of fields over a larger portion of the region than in the lower zones. Even in the Hopi country less than 3 percent of the area is actually farmed. Fig. 3 shows that there are many portions of the zone of favorable climate (rainfall 9 to 13 inches) in which there are few fields and in which the population is small. Thus the favorability of the Hopi country is dependent on some factor other than climate. This factor is its physiography, for it is characterized by wide, frequently flooded valleys and the presence of unusually large quantities of wind-blown sand both of which increase the supply of ground-water available both to plants and to man.

## SOILS

The agricultural soils of the Hopi country are almost entirely transported. Fields are usually located in areas of soil accumulation so that almost no soils in which crops are grown ever have a chance to develop profiles. The usual classification of soils is thus of little significance for Hopi agriculture. In a general way they are classified as follows:

- I. Soils transported by water (alluvial soils)
  - A. Clayey soils—apt to be alkaline
  - B. Sandy soils—well drained
- II. Soils derived by slope wash on steep mesa sides (colluvial soils)—are gravelly, sandy or clayey
- III. Soils transported by the wind (eolian soils)
  - A. Active dunes
  - B. Ancient dunes, usually containing caliche.

[11] Colton, 1937.

Soils transported by water are the most important class because fields irrigated by flood waters are planted on this type. Such soils may be entirely clayey silt, sand or loam, with all transitions between, depending on the source of the material transported. The more clayey soils are apt to be alkaline because they cannot be well drained in every location, for flood waters are apt to be ponded on them and, not being able to sink into the ground, dry up and deposit salts. There are areas in the Hopi country, otherwise ideally situated for farming, where there are no fields because of a clayey soil and poor drainage. The clay flat at the Naha well in the Jeddito valley may be such an area. The soils in the Oraibi Valley and in the Polacca Valley are generally more clayey than those in the Dinnebito or Jeddito Valleys, probably because the Mancos shale supplies more of the debris of the Polacca and Oraibi Washes. The upper portion of the Jeddito Valley contains only areas of sandy rocks and therefore the soils of the valley are sandy and porous.

A few farms are found on the steep mesa edges or on benches of mesas where soil composed of dune sand, blocks of debris, pottery fragments, trash and weathered shale, has collected by slope wash. These soils are very variable in texture but are relatively porous.

The greater part of the Hopi country is underlain by sandy soils transported by the wind. Wind-blown sand mantles all the interstream divides as well as the mesa edges and mesa tops. The dunes covering the lower plateaus of the southern three quarters of the Hopi Reservation are mostly very ancient and now fixed by vegetation. This is true of the dunes far back on the mesa tops. The sand of these areas has been subjected to weathering for several thousands of years and on this account has developed thin films of caliche around the sand grains. In some places rainwash has altered and subdued the form of the dunes and concentrated the finer material in hollows and low places. But few fields are planted in these areas and the soil type is of minor economic importance.

Close to the mesa edges and around the foot of the mesas fresh dune sand is piled up in many large dunes, either active now or partially fixed. The soils of these dunes contain very little material not classified as sand. Fields are commonly placed on such dune sand because of its great waterholding capacity.

## CLASSIFICATION OF FIELDS

The Hopi apparently have an excellent practical knowledge of the action of physiographic processes, for the position of their fields is closely related to the concentration of surface runoff and the flow of ground water. Fields on dunes are located in the proper place so as to take full advantage of the moisture available in them, and the position and construction of the wind breaks attest to the Hopi's knowledge of eolian processes.

Fields are first classified on the basis of their water supply, which in turn depends upon their physiographic position. There are four main classes which may be further subdivided on the basis of position or type of soil:

- I. Fields watered by surface runoff (flood-water farming)
  1. Akchin fields (at arroyo mouth)
  2. On floodplains of large streams
  3. On flood terraces of large arroyos
  4. In bottoms of small arroyos
  5. Trinchera fields (on artificial terraces in drainage ways)
  6. Watered by hillside wash (probably not found in Hopi country)
- II. Fields watered by rainfall
  1. Sand dune agriculture—sandy soil
  2. In alluvial and other soils (in higher parts of Navaho country)
- III. Fields watered by underground seepage (seepage fields)
  1. In dune sand
  2. In colluvial soils
  3. In dune hollows
- IV. Irrigated fields (usually in colluvial and alluvial soils)
  1. Irrigated by diversion of permanent streams (not found in Hopi Reservation but common at Moenkopi)
  2. Irrigated from springs

Of the four main types of water supply, fields watered by surface runoff are most important. Flood-water farming is the main agricultural practice and about 73 percent of the cultivated land is farmed in this way. The remaining 27 percent is mostly farmed by the use of sand dune agriculture, a form of "dry" farming. Seepage fields and irrigated gardens occupy only a small part of the land. Only 11 acres in District 6 (Hopi Reservation) are watered by springs but this small acreage is of very large value both because the crop is somewhat more desirable, and because it is free or almost free of risk of loss.

## FLOOD-WATER FARMING

### General Statement

On ordinary farms of the eastern United States, crops are watered by the rain that actually falls on the field and by the moisture that is stored in the ground between rains, but the rainfall in the Hopi country is inadequate for such farming. In flood-water farming the crops are watered by the runoff of an area much larger than the area actually cultivated. The moisture is stored in the soil between floods and provides a constant water supply for the plants except during long droughts. Flood-water fields are thus always located in a water course or adjacent to a water course, in such a position that during a flood large quantities of water will pass over the field, but not so rapidly as to wash out the crop. In the Hopi country the water courses are dry arroyos or washes which flow after every large rain in their drainage area, but which are dry between rains. On the watersheds of such streams, light falls of rain or heavy rains sink rapidly into the ground. When after continued rain the upper layers become saturated, runoff begins and the intricate network of runnels, gullies, arroyos, and washes begins to carry more and more water as muddy spates or floods. The peak flood in a large arroyo in the Hopi country occurs some time after the beginning of the rain and water will flow for several hours after the rain ceases because of the excess of water that has seeped into the ground. The larger washes may flow for several days after a heavy rain. A field located so as to catch part of the flood of an arroyo will thus receive a larger quantity of water and be soaked for a much longer time than any piece of ground not in a water course or on a floodplain.

### Akchin Fields

The most common location for a flood-water field in the Hopi country is on an arroyo of intermediate size at its so-called mouth or at the place where there ceases to be a channel and the water spreads. An arroyo starts its course on steep slopes, where the quantity of water flowing with great velocity erodes its walls and banks. Further down the stream gradient flattens and the load of silt being carried in the water increases. Finally a point is reached where the stream can no longer erode but must deposit its load. Here the channel ceases rather abuptly and a shallow fan is built up, over which the water spreads. This is the

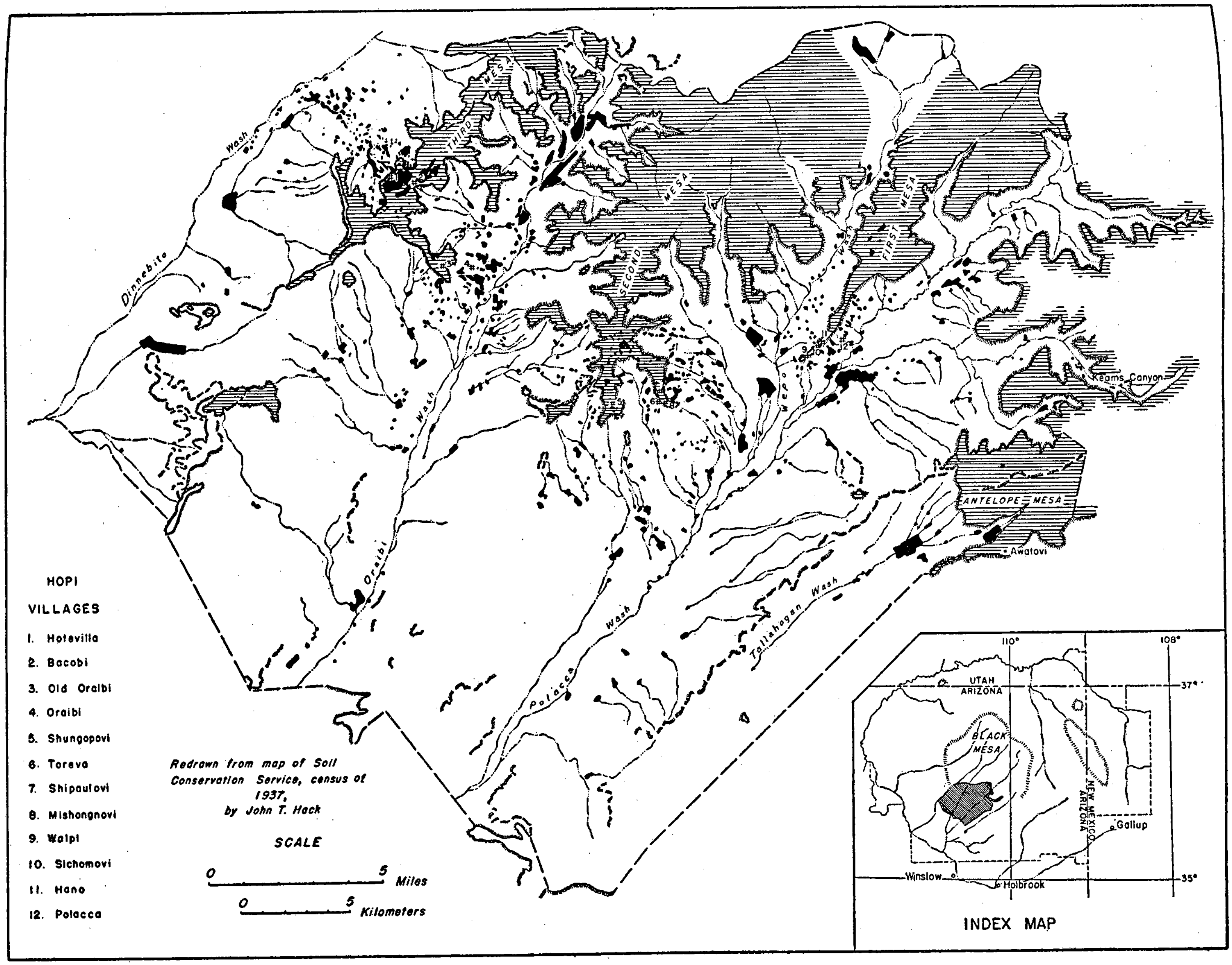


FIG. 13. Cultivated fields in the Hopi country, shown by solid black areas.

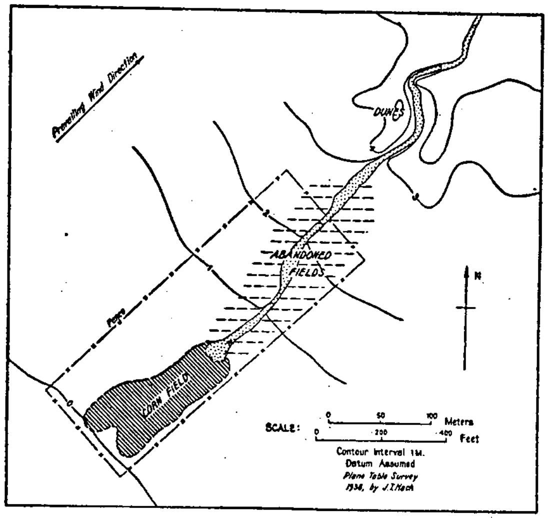


FIG. 14. Cultivated akchin field in the Tallahogan Valley.

arroyo mouth, called the "akchin" by the Papago Indians and accepted as a technical term by Bryan.[12] The akchin is a favored place for the location of a field because the runoff of the entire watershed of the arroyo, which has been concentrated in the stream channel, spreads out naturally over a relatively smooth surface without the aid of artificial spreading.

Many akchin fields are shown on the map, fig. 13. At present this is by far the most common type of field in the Hopi country. Their relative number would be strikingly shown on the map had the minor watercourses been indicated. The akchin of an arroyo is not a fixed location, because its position depends upon the ratio of the velocity of the flowing water to the relative volume of debris carried. In one flood the critical point at which deposition occurs may be downstream from the similar point for another flood. The result is that the alluvial fan produced by one flood may be channelled by the next and a new fan will form below. Thus the akchin is really an elongate area which is subject to channelling and may change its shape from one flood period to the next. Sometimes it may even be that the whole akchin will move upstream or downstream.

Fig. 14 shows an akchin field which has changed its position and which is located on a shallow alluvial fan. The field was formerly higher upstream. The map also shows the effect of the wind. High dunes are located just above the akchin where sand has collected after being blown off the field. Fields are ideal areas for the wind to pick up sand, for in order to farm, the fields must be cleared of shrubs and weeds, and since there is a wide space between plants the wind has a clean sweep. This sand is an important factor in the prevention of channelling of the akchin and also it tends to maintain it in a stable position since it hinders the eroding work of the floods.

Fig. 15 shows a typical Hopi farm. The house in the center of the farm is occupied by the farmer and his family during the growing season, for the location is about 8 miles from Sichomovi where he lives during the largest part of the year. The small arroyo on the left waters a melon patch, where a small earthen dike or spreader is set up at the top part of the akchin artificially to prevent channelling or washing out of the crop during floods. The cornfield on the right of the farm is watered by a much larger arroyo. The course of the floodwater across the field is in part controlled by the labor of the farmer who aids in spreading the water by digging channels to areas that are in danger of being left dry. One can see the Hopi farmers out working in the fields during almost every flood of the growing season. Sometimes water will be diverted to each plant individually if there is danger from drought. A fence now surrounds the field. Vegetation grows along its edge and the wind and water tend to pile up debris along it. The result is a ridge of sand two or three feet high, at the north end of the field. Even without a fence, sand piles up into a ridge at the lower end of the field if the wind blows in the right direction, for this is the limit of the cleared land and the wind is apt to scour out the sandy alluvial soil of the akchin and blow it off the cleared area onto the more thickly overgrown areas just surrounding it. Such a ridge of sand of course helps to stabilize the position of the field and to hold the water for a longer period of time. Such ridges are so common that abandoned fields may be located by them. In airplane photographs they produce a rectilinear criss-cross pattern on the ground where there have been many fields with changing positions. The action of the wind as well as the artificial spreaders of the farmer have the effect of hindering changes in the stream gradient. Thus akchin farming in no way favors the cutting of arroyos but in fact it rather has a tendency to prevent it.

[12] Bryan, 1929b.

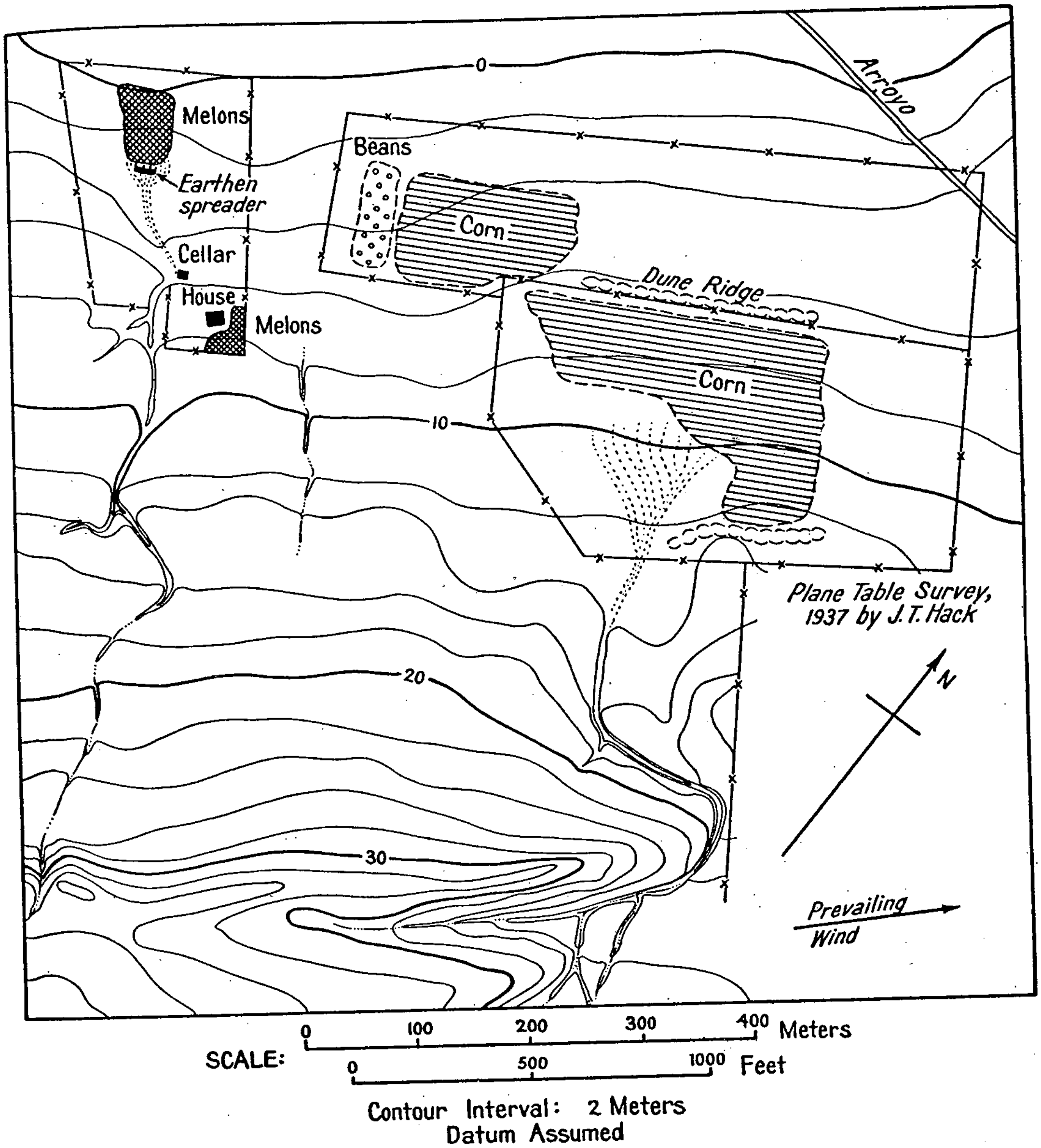


FIG. 15. A typical group of fields of the akchin type, worked by one Hopi, in the Tallahogan Valley.

### Fields Located on Floodplains of Streams

Another common location for fields is a position along the course of a shallow arroyo where the water will spread over a wide area during a flood. Shallow arroyos like the Tallahogan Wash vary considerably in depth along their courses and in some places are so shallow that the water can easily be diverted by earthen spreaders. A field located in such a position is in reality an akchin field even though the arroyo on which it is located is a large one and continues as such below the field.

Before the present cycle of arroyo cutting began (in 1900 in the Oraibi Valley and in 1910? in the Polacca Valley) many fields were located along the main streams. The Indians at Oraibi are said to have farmed by the use of the floodwaters of the main stream of the Oraibi Valley and to have had large spreaders and ditches which con-

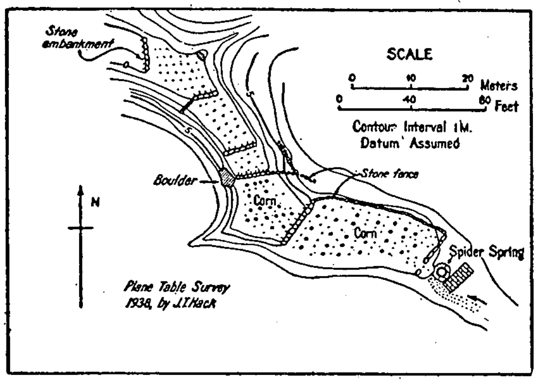


FIG. 16. Trinchera field in an arroyo tributary to the Wepo Wash, below the village of Hano. The gully walls are rock.

trolled the course of the floods. (see page 58). At the present time the Tallahogan Wash is the only wash of large size which is now shallow enough to flood its banks, and it does so only in small portions of its course.

Many farms which are adjacent to the Polacca Wash are visible in fig. 13. These are all akchin fields watered by tributaries of the Polacca which have never cut through the alluvium. Some of these tributaries are quite large and water many fields. If the present cycle of erosion continues and headward cutting proceeds from the main arroyo channels, eventually these akchin fields will be destroyed. In a long enough period of time all the tributary streams will be graded to the main streams and incised.

### Fields on Low Flood Terraces of Large Arroyos

Most of the large arroyos of the Hopi country have low but wide terraces in them, which are usually about 10 to 15 feet above the stream bed. These terraces form just below the level of the highest floods, and represent the new floodplains which are beginning to form above the stream beds of the incised arroyos by lateral migration of the streams. These terraces or incipient flood plains are thus overspread during all large floods. In lesser floods they are moistened by underground seepage of water. They are favored locations for cornfields, many of which are seen on the flood terraces of the Oraibi Wash. They have the disadvantage of being subject to destruction by violent floods.

### Fields in the Bottoms of Arroyos

Fields are occasionally planted in the bottoms of arroyos. These situations, like fields on terraces in arroyos, are subject to the danger of being washed away during a flood. Accordingly only arroyos which have small drainage areas are suitable.

### Trinchera Fields

A field in a small arroyo bottom can be greatly improved and made relatively safe from violent floods by building stone dams across the arroyo, making a series of terraces, called trinchera plots. The term, trinchera, has been used to describe terraces constructed of stone work on hillsides in Mexico.[13] Ordinarily trincheras are thought of as extending around a hillside. In the Hopi country trincheras are located principally in small arroyos on mesa sides and are constructed for the purpose of holding soil and controlling the course of flood-waters. Some trincheras, or terraces built of stone, are found on hillsides in irrigated gardens, and are described on page 37.

Fig. 16 shows a typical trinchera field at Spider Spring below the village of Hano. A rock-walled gully cutting through a steeply inclined landslide block is dammed in several places by small checks made with piles of small sandstone blocks and brush, making several flat, even terraces. Corn is the crop planted in these situations, which is nearly always of "early" type. It is planted in April, long before the date of the last killing frost in Spring, and is harvested in July. These localities in narrow gullies with steep gradients are likely to be frost free on cold nights as there is always a good circulation of air in a gully, and nocturnal radiation from the bare rock gully walls should help warm the plants. It is believed that the Hopi go to a great deal of trouble to make such gullies suitable for planting, because of the value of the early corn crop, which is associated with feasts and celebration.

### Fields Watered by Slope Wash

Bryan describes fields watered simply by slope wash at the break in slope on a valley side.[14] Such fields have not been observed in the Hopi country, probably because the valley sides are usually underlain by a very sandy alluvium or by dune sand, which banks up against the sandstone cliffs. There is little runoff from such material. The

[13] Sauer and Brand, 1931.

[14] Bryan, 1929b.

runoff comes principally from the mesa walls themselves and flows in the arroyo courses to the point where it spreads out at the akchins on the valley floor.

### Relation of Cultivated Areas to Watersheds

With the exception of the type cited above, all flood-water fields depend on the concentration of the runoff of a much larger area than that of the field itself. This volume of water, having been concentrated, must again be spread out evenly enough and gently enough so as not to wash out

either flat mesa top or low plateau surface covered with old dunes and therefore has almost no runoff. Thus actually about 3 to 4 percent of the area on which runoff takes place can be said to be cultivated. This figure is comparable to the percentage arrived at from fig. 17.

The main streams of the Hopi country, whose watersheds are principally on Black Mesa are now deeply incised. Before this dissection occurred the runoff of an area many times larger than the Hopi country was brought into the Hopi country and there spread over the flood plains of its master streams. In other words the farm land of the Hopi country was watered not only by the

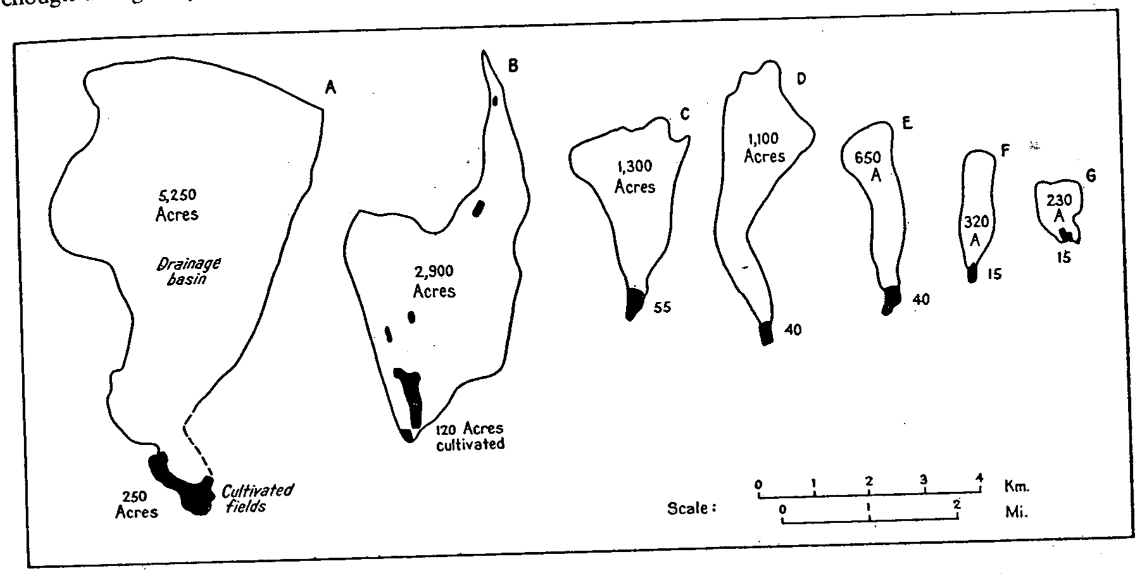


Fig. 17. Relationship between areas of cultivated akchin fields and the areas of the watersheds which supply them with water.

the plants. Where the runoff of a large watershed is concentrated a large field can be placed. Where the watershed is small, the field must be small. Actually there seems to be in the Hopi country a fairly constant ratio between the size of fields and the watersheds which supply them. Several fields and watersheds are shown in fig. 17. In these fields the area farmed is between 3 to 6 percent of the area of the whole drainage basin. The ratio varies considerably because of differences in amount of runoff from one watershed to another. Runoff from sandy watersheds is less than from those that are mostly bare shale slopes. In the whole Hopi country the area cultivated by flood-water farming is less than 2 percent of the total area. About one half of the area is

runoff from land within its own boundaries but also by the runoff from the upper drainage basins of the Tusayan Washes. Thus the area which could be farmed must have been much larger than it is today. The effect of the recent epicycle of erosion has been not only to reduce the amount of flood-water farming, but to shift the position of fields from the floodplains of large streams to the akchins of tributary streams. Inasmuch as the Hopi country is characterized by unusually broad valleys, which contain many streams tributary to the main through-flowing streams or washes, the effect of arroyo cutting is less devastating to its agricultural inhabitants than in other areas where farmers are dependent solely on the flood-water of the main streams.

## SAND DUNE AGRICULTURE

### Principles

Fields on the bare sandy areas of mesa tops and mesa slopes are second in area to flood-water fields. There is no obvious source of moisture for these fields except that which falls as rain. On less porous soils, rainfall alone is inadequate as a source of moisture, but it is apparent that crops can be grown in dune sand, owing to its superiority as a storage reservoir for moisture. There are several sub-types of this sand dune agriculture all of which depend on the ability of the highly porous sand to store and conserve moisture. By far the most common situation of sand dune fields is where a more or less thin cover of dune sand (one half to three feet thick) rests on a less pervious sub soil, which being on a mesa top or mesa side is probably colluvial, derived by rainwash and slope wash. Many Hopi fields are known to be planted on a thin cover of sand. When abandoned the sand is blown away and reveals the thicker colluvial soil or bare rock below.

Colton[15] has compared Indian farming on sand with the well-known "dry farming" as developed and practiced in the Great Plains. In this method of farming penetration of moisture into the soil is promoted and the moisture obtained is conserved. The essential procedure is to treat the top soil differently from the lower layers of the soil. The land is plowed deeply and thus loosened at depth. Plowing is followed by light packing of the surface and then by deep planting. After each rain the top layer of the soil is harrowed to produce a dry mulch which invites penetration of rain and prevents evaporation of the soil moisture below. In Hopi sand dune agriculture, the loose surface of the sand acts as a dry mulch which invites the absorption of rain and which also prevents evaporation. So far as penetration of moisture is concerned the sand is more effective than the dust mulch of the "dry farming" method, as it is well known that there is no runoff from dune sand even in the heaviest rains. Furthermore only a thin layer of the sand dries out and the sand below will remain saturated for a long time by the water held up by the less pervious soil below.

Many sand dune fields are planted on large climbing dunes or steep dune covered slopes of a mesa, where the sand must be thick. A common position for fields is near the base of these climbing dunes. Here water may be supplied by underground seepage from the upper dune slopes, so that some of the fields in these positions may come under the heading of seepage fields.

Some sand dune fields, however, seem to require some other source of moisture to start plant growth. Fields on the lower slopes of the mesa walls, in many places seem to be planted on dune sand which is perhaps much over 10 feet thick. Ground water must be present at depth in these dunes and it can probably be reached by the roots of mature plants. It is doubtful, however, that this ground water is available to young plants. In sand the size of that of the Hopi country, water probably does not rise more than 3 feet above the water table because of capillary action, and it is not likely that the water table is within 3 feet of the surface in all dunes on which crops are planted.

Studies of moisture in dune sand have been made in the Kara-kum desert of Turkestan, an area with a climate similar to the Hopi country, by Doubiansky.[16] His observations show that below a surface of shifting sand where ground water is present at depth there is always a zone of moisture (2 or 3 percent) at a depth of 40 to 120 centimeters. Even though this zone of moisture is underlain by dry sand, it persists throughout the dry season, and is available for use by plants.

Doubiansky calls this the sub-superficial moisture horizon. He believes that moisture is concentrated at this shallow depth because diurnal changes of temperature in the sand cause condensation of the vapor evaporated from the ground water at great depth.

It may be that there is a sub-superficial horizon of moisture in the dunes of the Hopi country which aids the growth of the young plants during the dry spring.

Thus the sand dune fields depend on the conservation of moisture by the superficial layer of dry shifting sand, and the prevention of runoff. There must be some soil moisture in the sand to start plant growth, but even so growth is probably not possible if the depth to the capillary fringe above the water table or to a heavier clayey soil, is too great for the plant roots to reach it.

### Crop Practices

Many crops are planted in sand dune fields. The most conspicuous crop near the Hopi towns is peaches, a crop introduced by the Spaniards. Apricots and apples are also found in these fields,

[15] Colton, 1932, p. 588.
[16] Doubiansky, 1928, p. 238.

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but the most important sand dune crop is certainly beans. Although corn is the staple Hopi food, in areas where sand dune agriculture is practiced beans seem to be more abundant than corn. Much corn is also grown by this method, however. Melons, an important item in Hopi food supply, are almost entirely confined to flood-water fields.

An explanation may be found for this selection of crops in the root habits of the plants. Melons are conspicuously absent from sand dune fields. This is probably because they have long, branching lateral roots, adapted only to feed on soil moisture and have no deep roots to reach water at depth.[17] Beans have long branching roots and are very efficient in utilizing soil water, more so than corn. They also have deep roots which may go to some depth for ground water.[18] They thus may be better adapted to this type of situation than corn, for they may get their start by utilizing the scant soil moisture, and when grown penetrate the zone of saturation at depth, or the capillary fringe above it. Corn, peaches, and other fruits also have deep roots.

Sand dune fields are the only type which leave clues by which the archaeologist may recognize the places where they once existed, for elaborate stone work is used in these fields, to protect the plants from damage by blowing sand. The principal disadvantage of this type of dry farming is that in order to conserve the moisture in the dunes, a large area around the fields must be cleared of natural vegetation. This leaves the crop plants completely exposed to the wind, which is most violent in the spring when the tender young plants are just coming to the surface. Also the dune sand is looser and easier for the wind to move than the siltier sand of the flood-water fields. Elaborate methods must thus be used to protect the plants from being torn to shreds. In fields not greatly exposed, as on rolling mesa tops, large stones or tin cans are placed around each plant. On exposed slopes more extensive measures must be undertaken. Many of the fields are located on a thin sand mantle resting on less pervious soil or bed rock, and the sand itself is in danger of being swept away, when cleared for planting. To hold it, lines of brush are placed in rows about 2 to 5 meters apart. The brush is held in place by heavy stones which become buried by the sand leaving only the brush projecting from 1 to 3 feet above

[17] Weaver and Bruner, 1927.
[18] Weaver and Bruner, 1927.

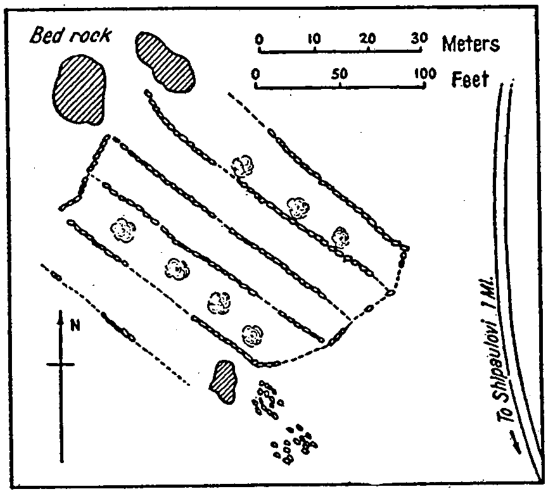


FIG. 18. Abandoned apple orchard of the sand dune type on Second Mesa, near the village of Shipaulovi. This map shows the use of lines of stones to keep the sand from blowing away (see pl. VIa). These stones once held down lines of brush, which are now destroyed.

the sand. When a field thus protected is abandoned, the brush gradually rots or is cut away by moving sand and eventually the whole area is blown clear of sand leaving only the lines of stones as evidence of the former existence of a field. On Second Mesa an abandoned apple orchard was found with most of the sand blown away, but with rotten brush still piled up under the parallel rows of stones (fig. 18, and pl. VIa). Ancient lines of stones were found in abundance in the Jeddito Valley. They are described in Chapter VI.

### Favorite Locations

Sand dune fields are probably most common on the mesa walls where the cover of dune sand on colluvial soil is thin, or near the base of great climbing or falling dunes banked up against the mesa sides. Another common location is on ancient dunes on the mesa tops which have been cleared of vegetation and kept from becoming active either by the use of wind breaks, or by leaving large uncleared areas between. Sand dune agriculture is not practiced in areas of active dunes.

The largest development of this kind of agriculture is at the village of Hotevilla where according to U. S. Soil Conservation statistics (1937) over 60 percent of the cultivated land is watered by rainfall only, and thus is farmed by the method of sand dune agriculture. This figure is in great contrast to the figure for the whole Hopi coun-

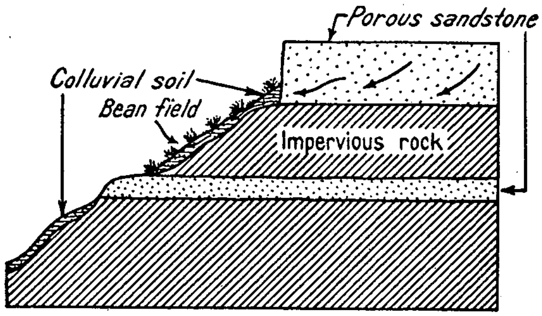


FIG. 19. Cross section of a seepage field below Old Oraibi on the east side of Third Mesa (see pl. VIc).

try, in which less than 27 percent of the land is watered by rainfall only. The inhabitants of Hotevilla are unique in preferring this kind of agriculture. It is a particularly favorable place for it, however, because dune sand has here banked up against the side of the mesa and many good sites for fields are available near the town. At Hotevilla beans equal corn in importance as food, probably due to the fact that this type of farming is better suited to beans. Such variation from the usual practice of Hopi farming may aid in the explanation of the quarrel at Oraibi which ended in the migration of a portion of its inhabitants to Hotevilla and the founding of that town, in the year 1906.[19] In 1893 the inhabitants of Oraibi diverted water from the main Oraibi wash for flood-water farming. By 1902 the wash was 10 or 12 feet deep and 20 to 30 feet wide; by 1905 it was deeply entrenched.[20] In 1906 the quarrel at Oraibi culminated in the migration to Hotevilla, a place where the inhabitants do not depend so much on flood-water farming. It may be that one of the underlying causes for the split at Oraibi was the crowding of farmers, as one field after another was destroyed by the cutting of the wash. Three informants (White, Hubbell, Nequatewa) assured the writer that no quarrel over land holdings was involved but the coincidence in time with the cutting of the wash is circumstantial evidence which should not be ignored. It may have been largely responsible for causing unrest and dissension which led to a quarrel over an entirely different matter.

## FIELDS ON COLLUVIAL SOIL WATERED BY RAINFALL ONLY

In regions of higher rainfall it is possible to farm on more clayey alluvial soils, or colluvial soils, without making use of the concentrated runoff of a larger area. Several such "dry" farms have been seen by the writer on the Defiance Plateau in the zone of yellow pine, where the mean annual precipitation is over 16 inches. But these fields suffer from a short growing season. None are found in the Hopi country.

## SEEPAGE FIELDS

Seepage fields like the irrigated fields depend for their water supply on reservoirs of ground water. In the Hopi country the principal springs are found close to the mesa tops along the base of the massive sandstone cap rock. Between the few springs water constantly seeps out, and in many places at this level abundant vegetation grows in the moist soil. The base of the massive sandstone is thus a favored place for a field if there is any colluvial soil available under it. A few small fields of this type are found in the Hopi country as illustrated in fig. 19, and pl. VIc, but the occurrence of colluvial soil at this horizon is rare. Dune sand, however, frequently covers the edge of the mesa and is kept moist by the underground seepage of water. Fields in dune sand are very common at this horizon. Naturally such a water supply is more reliable than rainfall alone. It is thought that many of the peach orchards on the steep sandy slopes of First Mesa are watered by ground water issuing from the cap rock of the mesa. Actually it is often impossible to distinguish a field of this type from a "dry" sand dune field.

In the often cited oases of the Sahara Desert, groves of date palms are grown in the underground water supply available in the dune hollows.[21] Farming in dune hollows is done on a smaller scale in the Hopi country, but the principal is the same. Seeps are of common occurrence in dune hollows (see fig. 6), and in the dunes of First Mesa this occurrence of ground water is utilized for agriculture.

## IRRIGATION

### General

There are two kinds of irrigation practiced by the Hopi. At Moenkopi, which is a distant outpost of the Hopi country, not in the reservation, the Indians irrigate the alluvial floor of Moenkopi canyon by diverting the water of the wash, which

[19] Colton and Baxter, 1932, p. 46.
[20] Communication with Mr. Lorenzo Hubbell.
[21] Brunhes, 1920.

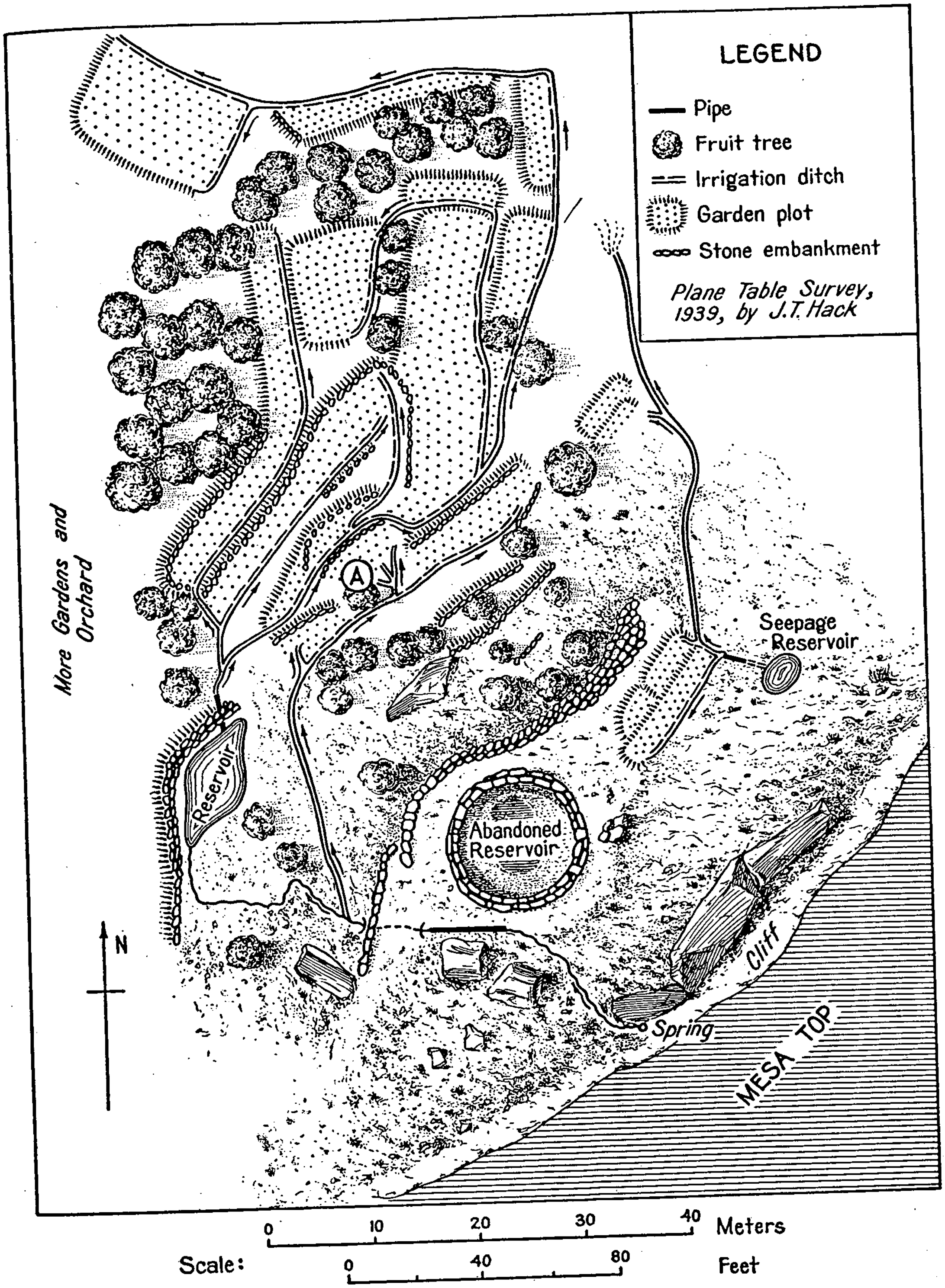


FIG. 20. Sketch map of a portion of the irrigated gardens in Tallahogan Canyon, north of the ruin of Awatovi, showing the method of watering.

is a permanent stream having an average discharge of about 10 second feet. The water is run into long supply ditches along the base of the canyon wall, and from there it is fed to field laterals at regular intervals and spread over the fields, which are planted on a low, but wide alluvial terrace on the canyon floor. Corn is the principal crop. For a more complete description see Gregory's study of this area.[22]

In the Hopi country itself, there is no large supply of permanent water and what little there is is derived from springs. The largest spring used for irrigation is the Wepo Spring on First Mesa (fig. 8) which has a flow of over 30 gallons a minute. Other large Springs are Tallahogan (5–10 gallons a minute), Canelva, and Hotevilla Spring. These are all mesa springs high on the mesa side. The water is conserved in a small reservoir, and from there fed when needed to the fields below by means of small ditches. All together there are only eleven acres of land thus irrigated. Nevertheless the irrigated land is of importance to the Hopi. The great labor expended in watering by this means justifies the planting of only the most desirable delicacies. The most abundant plants are squash, corn, turnips, carrots, cabbage, onions, chile, peaches, apricots, and apples. In addition many rarer plants are grown mixed with the others, such as tobacco and cotton for ceremonial purposes, and plants used for vegetable dyes.

Only clayey alluvial soils are suitable for garden areas. Sand is too porous and does not permit the water to run down the surface of the ground from the spring to the field. Thus nearly all the irrigated gardens are on steep slopes high on the mesa sides, in areas more or less free of sand.

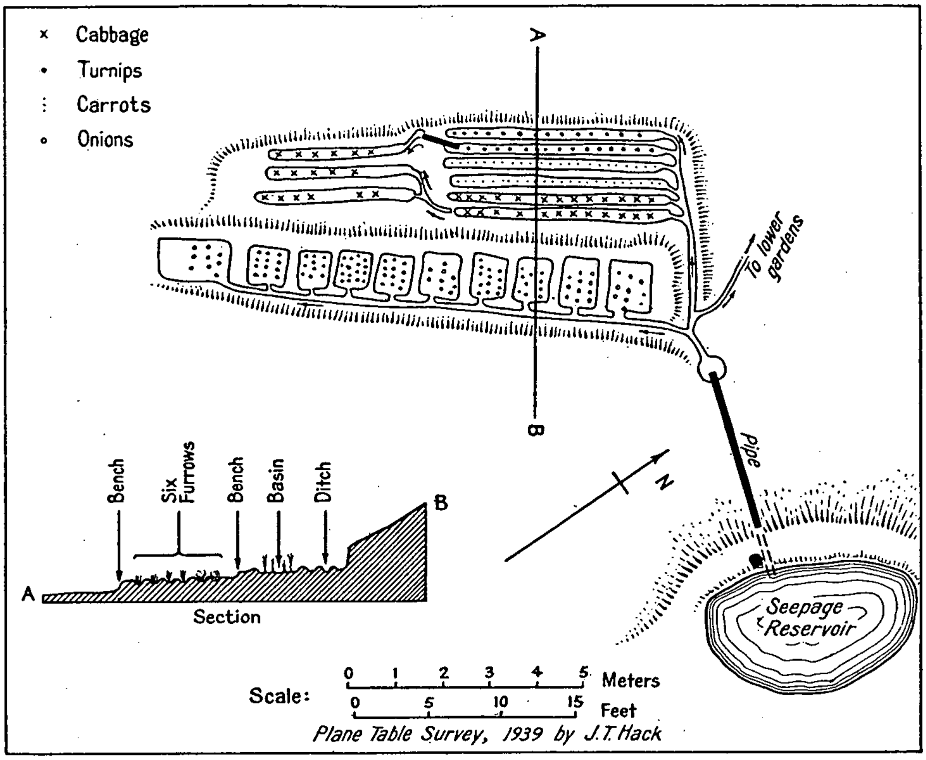


Fig. 21. Map and cross section of a single garden plot in the Tallahogan gardens. Each living plant is shown.

### The Tallahogan Gardens as an Example of the Method of Watering

The gardens at Tallahogan Canyon close to Awatovi, are quite similar to the other gardens and serve as a typical example. They occupy a small area, but probably have over 25 owners, and contain numerous garden plots. On the south side of Tallahogan Canyon rather large springs break out in several places near the top of the

[22] Gregory, 1915b.

valley wall. Though dune sand covers much of this wall there are areas of colluvial soil watered by springs on which crops are planted. A portion of such an area is shown in fig. 20 (see also pls. VId and VII). The spring breaks out at the base of a sandstone cliff, about 25 feet high. The water runs down a steep slope in a little brooklet, surrounded by a thick growth of fragrant mint, to a small pool where it is caught and diverted to a pipe, which serves as a water fountain for the inhabitants of the houses nearby. In recent years a large stone reservoir was built just below the spring but it did not hold water and had to be abandoned. It still collects a little water, however, which seeps into the ground and waters the peach trees below by underground seepage. The main flow of water runs from the pipe into a tunnel in a stone terrace, and down to a cruder but more effective earth and stone reservoir. From there the distribution of the water through the gardens begins. A pipe taps the reservoir and can be stopped up when irrigation is not going on. The other end of the pipe feeds a small supply ditch about 6 inches wide and 4 inches deep which runs down to the various fields. Diversion to the proper place is carried out by damming the ditches and openings, not to be used, with stones and mud. The water is carefully guided by each owner, by means of these little artificial runnels and tiny earthen dams, to each plant around which one can see patches of wet ground after irrigation (pl. VIIIa). Apples, peaches and apricots are planted between the irrigated garden plots, and on the steep hillside below the reservoirs. They are watered by the moisture which seeps into the ground from the channels, basins, and furrows of the gardens, for no drainage is provided. The water must escape through the porous soil.

The method of watering each garden plot is shown more clearly in fig. 21, which is a map of the garden plot to the northeast of the abandoned reservoir. This plot is fed by its own reservoir. There is no flowing spring here, but the reservoir is dug just below the level of seeps on the mesa wall and is kept full of water by underground seepage. As in the main reservoir a pipe leads to a supply ditch. Two kinds of irrigation are illustrated. The upper level of the garden represents the basin system, in which water is diverted to square, shallow basins individually. The onions planted here are allowed to soak in the water until it seeps into the ground. When not being flooded the entrance to each basin is closed by a dam of stones and mud. The lower garden or terrace represents a similar system in which the crops are planted in the bottoms of large furrows rather than basins.

Onions, cabbage, turnips, carrots, and chile are usually planted in regular basins and furrows as in fig. 21. Corn and squash frequently is watered in areas between, by individual runnels as at A, fig. 20. Tobacco and probably other rare plants are grown by scattering seeds, and watered by the excess water that escapes from basins and furrows.

### Terraces

As shown in fig. 20 the Tallahogan gardens contain many artificial terraces, or trincheras, which unlike the trincheras of flood-water fields are placed on the hillsides. The purpose of the terraces is obviously to provide roomy flat areas on the steep hillsides on which the crops can be planted in basins and furrows and fed with water from supply ditches. On steep hillsides the terraces are built of sandstone blocks. Such terraces average about 3 feet in height but may be as high as 10 feet. Lower down on flatter areas, earthen terraces are sufficient.

Such stone work is used throughout the Hopi country wherever this type of agriculture is practiced. At Hotevilla many closely huddled and picturesque stone terraces cling to the precipitous mesa wall directly beneath the village. They support lush-looking gardens, and make this place a favorite one for tourist visits.

### The Question of Spanish Origin

One of the most important questions in regard to this system of farming is whether or not it is of pre-Spanish origin. No stone work has been seen by the writer anywhere in the Jeddito Valley region (inhabited by the Hopi before Spanish time) which could be identified as the remains of such gardens. On the other hand it is possible but rather improbable that large enough springs have occurred only where they are now. Cruder types of irrigation without the use of stone embankments may have been practiced, which would leave no trace of their existence. There are now only eleven acres of these gardens in the Hopi country which furnish only delicacies and rare plants, many of which were unknown to the Hopi before the coming of the Spaniards. The native

## Chapter VI

# THE CHANGING ENVIRONMENT OF THE HOPI PEOPLE AND ITS EFFECT ON THEIR AGRICULTURAL ECONOMY

IN the preceding chapters the modern physical environment, the physical basis for agriculture, changes in climate, and the regime of surface streams have been discussed. The Hopi country is a land more favorable for a primitive agricultural settlement than other regions nearby. It lies in the most favorable climatic zone, one with a long enough growing season, and yet with enough rain for successful corn production by special methods. Because of its physiography it occupies a favorable part of this zone, where much dune sand makes for more porous soil and a greater water supply. The wide valleys offer large areas to be flooded by ephemeral streams.

Study of the ancient arroyo systems makes possible estimates of the relative amounts of agricultural lands in the past and study of dunes makes possible speculation on the broader problem of climatic change. By correlation of these events with general aspects of Pueblo and Hopi history, it is possible to gauge the importance of environmental change on their well being and cultural development.

## ANCIENT HOPI AGRICULTURE IN THE JEDDITO VALLEY

### General

There are two means of gauging the position of fields in the past. Sand dune fields, because they require the use of stone lines to hold down wind breaks, leave traces after they are abandoned. Thus the location and mapping of ancient fields of this type is possible. However, these fields make up only 20 percent of the acres planted today, and throughout the whole period of settlement may have been of minor importance. Flood-water fields are used for the bulk of the corn supply. They leave no permanent trace of their former presence when abandoned, but because they can be placed only where flood-waters spread, the position and relative size of ancient fields can be estimated by knowing the history of the watercourses. Other types of fields leave no traces and are of minor importance.

### Sand Dune Fields

Modern sand dune fields are common on Mesa tops and mesa edges near Hopi towns. In most cases the lines of stones used in the making of wind breaks cannot be seen, but when a field has been abandoned for a short time the sand is in part blown away, and the lines exposed, as illustrated in fig. 18.

Similar sets of stone lines are of common occurrence on the north rim of the Jeddito Valley, as shown in fig. 48. They are most abundant on the wide bench half way up the cliff edge, where the sand is thin and overlies shale or adobe slopes, but are also found on the mesa top in a few places near the cliff edge. Many more areas of stone lines may once have existed but are destroyed or buried by action of water and wind.

The most perfect example found of these ancient fields is shown in fig. 49 (Locality B, fig. 48) The area once farmed consists of a thin sheet of wind-blown sand which partially covers a large block of landslide débris. Rocks of this landslide block crop out through the sand in many places in the northern part of the area farmed. The ancient Hopi utilized these outcrops in making their pattern of wind breaks. The area is typical of the sand dune fields which utilize a thin cover of sand over a clay or colluvial soil, as a dry mulch in storing water.

At Locality A, fig. 48, was found an ancient sand dune field on the mesa top near the cliff edge, shown in detail in fig. 50. This area also has a thin sandy soil, but here it mantles the sandstone cap rock of the mesa rim. A small amount of water was undoubtedly furnished by runoff and underground seepage from the outcrops and sand dunes surrounding the area.

Other localities along the north valley wall are similar to localities A and B. In some cases the sandy soil is still preserved; in others it is washed or blown away. At locality C (fig. 48) a group of stone lines occurs on an ancient climbing dune, among a group of small Pueblo III ruins. One of the rooms abuts directly against a stone line and appears to have been built at a later time, al-

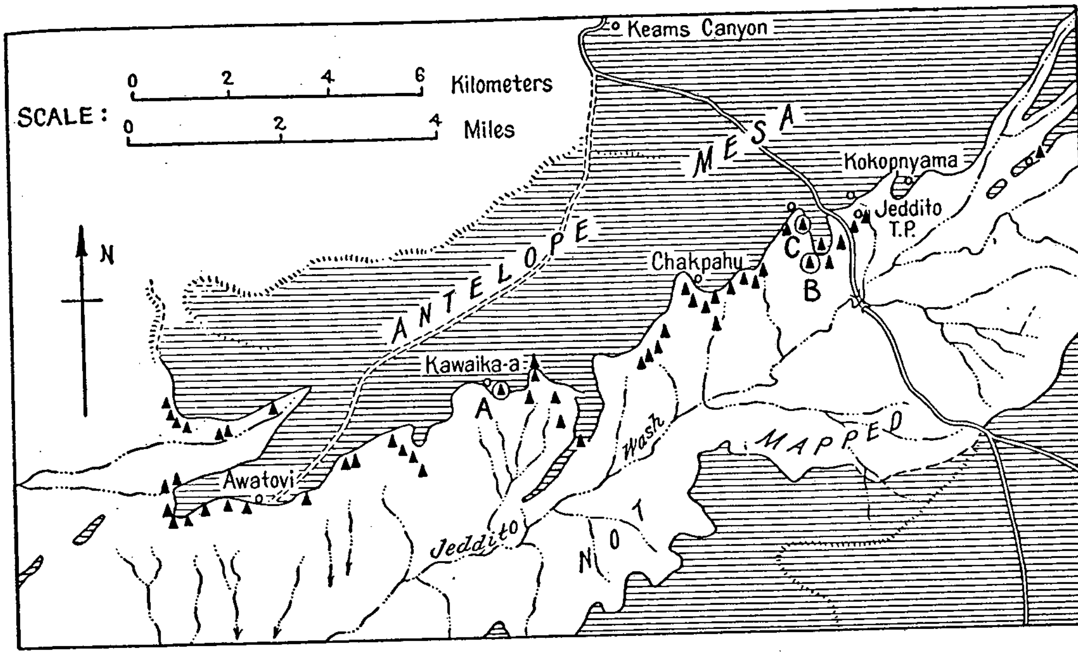


FIG. 48. Localities in the Jeddito Valley where the positions of ancient sand dune fields are recorded by areas of stone lines. Localities are shown by triangles.

though the evidence is not conclusive. This group of lines is then as old as Pueblo III and it is probable that this system of farming is a very ancient one.

All along the mesa edge, there is a definite relationships between the stone lines of ancient sand dune fields and areas where coal was mined and pottery fired. Ash heaps, which are the remains of places where pottery was fired with coal occur at many places along the valley wall.[1] Stone lines commonly occur nearby but not in the same places as the ash heaps. The ash heaps are often built on mining waste, not good soil for farming. The wind breaks and corn fields were apparently placed on undisturbed sandy soil nearby. The relationship is illustrated in fig. 51, which shows the distribution of ash heaps and stone lines on the wide bench of the cliff edge below Awatovi.

The close relationship between the loci of the two activities suggests that they were perhaps carried on simultaneously by the same individuals. One can readily imagine that the ancient Hopi women fired their pottery near the outcrops of coal and while engaged in this activity were able conveniently to tend small fields nearby which produced an extra supply of food.

[1] Hack, 1942.

Sand dune fields today occupy about 20 per cent of the land under cultivation by the Hopi. At Hotevilla, however, their importance is much greater, and they make up over 60 percent of the area cultivated. It is probably possible greatly to expand the area of this type of field all through the Hopi country, and in the Jeddito Valley sand dune fields may at times have been very important.

### FLOOD-WATER FARMING IN THE JEDDITO VALLEY

Flood-water fields, the type of greatest importance, are now almost the only type used in the Jeddito Valley. All the fields near the Jeddito Valley and Antelope Mesa ruins are shown in fig. 52. The only large fields not irrigated by floodwaters are those in Tallahogan Canyon, north of the ruin of Awatovi. This region was abandoned as a place of permanent habitation by the Hopi before 1700 A.D. and today the nearest Hopi village is about 8 miles away (See figs. 8 and 13). However, the people of First Mesa and Second Mesa still farm in the Tallahogan Valley which is inside the Hopi District 6. They have numerous small farm houses near these fields and occupy them during the planting and harvesting seasons, and at various times during the sum-

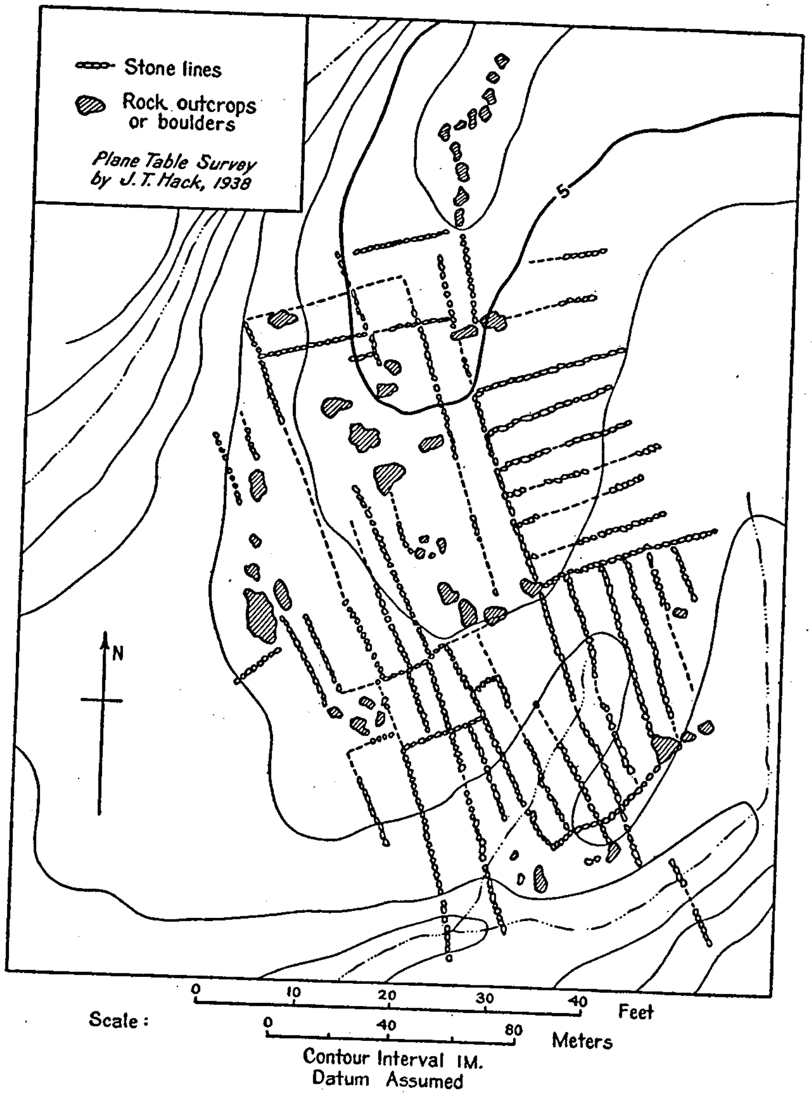


FIG. 49. Area of stone lines near Jeddito Trading Post (locality B, fig. 48).

mer. The Jeddito Valley, which is in District 7, is occupied by Navahos, except for one Hopi (married to a Navaho) who has a large house and farm near the wash below the ruin of Chakpahu.

The Navahos obtain a larger part of their income from stock raising than from agriculture, in contrast to the agricultural Hopi. Accordingly they use only the most economical methods of producing corn in large quantities, and do not resort to small sand dune fields which require more labor than flood-water fields.

Above the Naha well, all the fields are akchin fields at the ends of tributary arroyos which have not yet cut down to the grade of the main wash. But below the Winslow Road the Jeddito Wash becomes shallower, and the broad clay flats along its low banks are spread over by floods from many tributaries. Still farther downstream flood-waters of the Jeddito itself spread over the flats. Thus large fields watered by the runoff of the whole Jeddito Valley region can be located in this area. Its value is enhanced by the fact that below well No. 230 the wash has a small perennial flow of water. In September, 1939, it was flowing at the Winslow Road, after one of the driest summers ever experienced in the region.

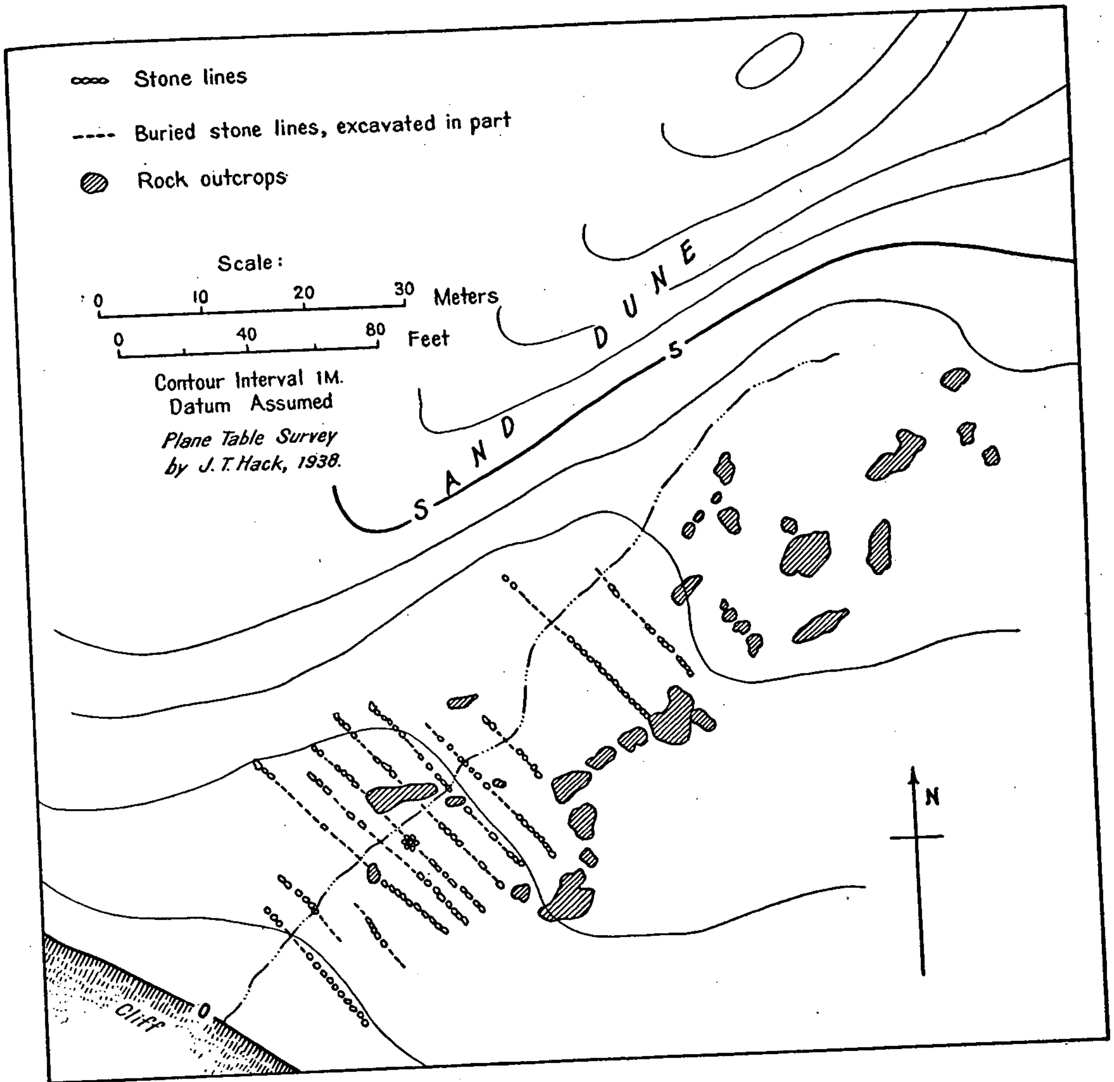


FIG. 50. Ancient sand dune field and area of stone lines near Kawaika-a, at locality A, fig. 48.

Akchin fields can be planted only where arroyos spread over the flats. Thus arroyos which are deeply incised all the way to the Jeddito Wash, are as useless for farming as the main wash itself is above the Winslow Road. These washes are shown in fig. 52. Before the present epicycle of erosion occurred, however, (1908–1920) they were also available. The restoration of the arroyos now deeply incised, not including the main Jeddito Wash, would probably increase the acreage available for flood-water farming by at least 25 percent. If the main wash could spread out over its banks along its whole course, the cultivatible acreage would be increased enormously.

As shown in Chapter V the history of the washes and their gradients is known for several periods of the past. This data can be used to show the amount of land available for farming. Fig. 53 is a series of sketch maps of the Jeddito Valley, showing the postulated condition of the surface drainage at various times, and the general areas that could have been farmed. Map 5 shows the Jeddito Wash and the fields of today. The dotted areas represent the general area overspread by floodwaters. The boundaries of these areas cannot be closely defined, as they change position from time to time and the fields must be moved with them; thus only zones of farming are shown.

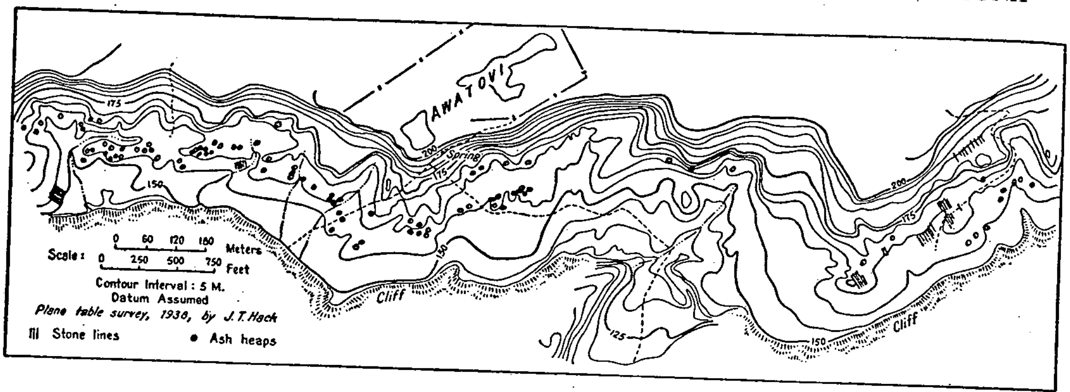


FIG. 51. Areas of stone lines on the bench beneath the ruin of Awatovi. Shows the relationship to ash heaps where pottery was fired.

Map 1 represents the conditions in the Tsegi period of deposition as they probably were during the later part of the first millennium A.D. At some time during this period the wash must have had a shallow channel over most of its course. The stream must have spread over the central portion of the valley floor. Numerous clay layers in the formation show that there were many areas of spreading waters. The drainage was probably carried not by a coherent arroyo system, but by a series of very shallow channels each of which ran only for a short distance.

As shown in Chapter V the lower part of the Jeddito Valley was covered by a thick mantle of sand dunes during all of Tsegi time so that the Jeddito Wash and all its drainage must have spread out somewhere near the end of Antelope Mesa. Conditions at this time were ideal for flood-water farming. All through the central portion of the valley, farms could have been located in thousands of places on the Tsegi formation. The only positions not flooded were probably the dune-covered and dissected slopes of the Jeddito terrace along the valley wall.

Toward the end of the Tsegi period, a lowering of stream gradients occurred. The mouth of the wash was forced downstream, and silt and clay was deposited on top of the dune barrier. Around 1200, the situation was probably as represented in map No. 2, still ideal for flood-water farming. Somewhere near the end of Pueblo III time, however, (the date is uncertain), the dune barrier in the center of the valley was finally covered by a thin deposit of silt, and the wash had established its course all the way to the Winslow Road and beyond. Then the dunes no longer acted as a barrier, and the wash became deeply incised, in most places to bed rock. Dissection continued until the Jeddito Wash and many tributaries flowed in arroyos as deep and even wider than those of today. It is not known how far down the valley dissection occurred. There may have been a shallow arroyo, or no arroyo in the lower valley, or dissection may have occurred all the way to the Little Colorado River.

At this time the area available for farming was small, probably even smaller than it is today, as shown in map 3. The Hopi may have resorted to sand dune agriculture for their main food supply. The Tallahogan Wash, however, and some tributaries of the Jeddito undoubtedly never cut deep enough arroyos to ruin all the areas of flood-water farming. The Tallahogan Wash is still blocked by sand dunes just as the Jeddito was until it broke through at the end of Pueblo III time.

In Pueblo IV time, the washes began aggrading their channels; tributary arroyos became filled and the areas available for flood-water farming again increased. By 1700 A.D. the stream system had reached the condition shown in map 4. Note that the akchin of the Jeddito Wash has never again risen above the dune barrier. As a result the gradient of the wash farther upstream never rose up to the level it had in Tsegi time. Thus even at the optimum of Naha time, the Jeddito Wash flowed in a fairly deep channel. Floodwater farming was possible, however, at the akchins of tributaries, and in the vicinity of the Winslow Road, at the mouth of the main wash.

This condition continued until after 1908, when the present epicycle of erosion began. The mouth of the Jeddito has moved far downstream and many, but not all of the tributaries, have been incised so that farming areas have been reduced.

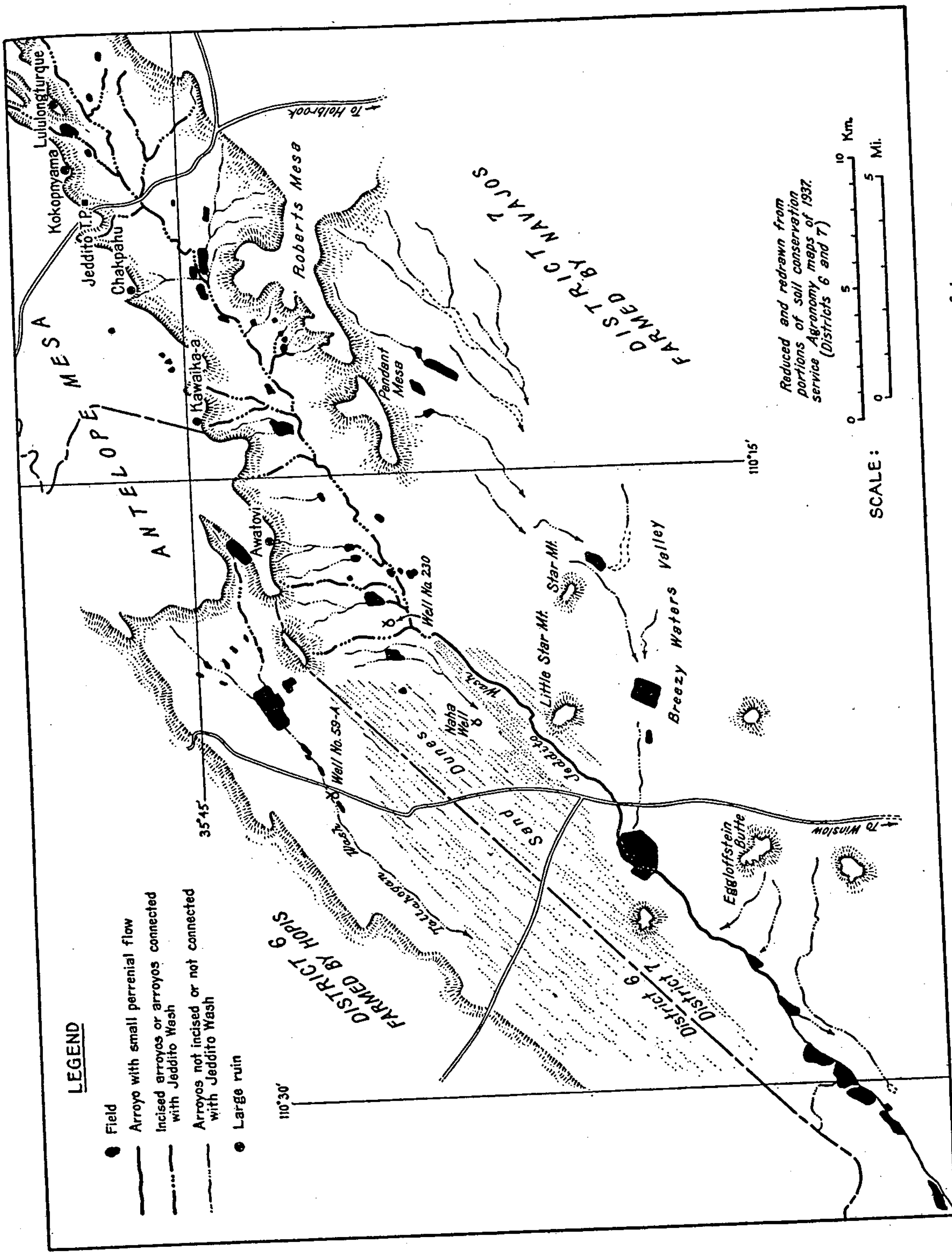


FIG. 52. Modern fields in the Jeddito Valley region. This map also shows the condition of the streams.

Thus Hopi farming in the Jeddito Valley was best in the first millennium A.D. Gradients undoubtedly changed from time to time, during this long period and affected the farming, but there was always a flood plain near the end of Antelope Mesa. In the Tsegi-Naha period of erosion, there was probably even less land for farming than there is today. In Naha time (Pueblo IV and V) conditions improved but never again reached the lush conditions of Tsegi time.

This history is in marked contrast to that of the other Tusayan Washes. The Dinnebito, Oraibi, Polacca, and Wepo Washes all rose above their former banks during Naha time, so that conditions for farming were as favorable as in Tsegi time. As shown on page 79, this may account for the abandonment of the pueblos of the Jeddito Valley region.

### Earlier History of the Jeddito Valley

No attempt has been made to work out conditions for farming earlier than late Tsegi time. The Hopi or their ancestors have occupied the region probably only since the later part of Tsegi time (since the time of Christ) and the earlier inhabitants, if any, were probably not agricultural people. Furthermore the older record of gradient changes is much more obscure. It is possible, however, to recognize a period of much greater dryness between 2000 and 5000 B.C. and a cooler wetter period, corresponding to the deposition of the Jeddito formation before 5000 B.C.

In the warm-dry period of erosion the region must have been unsuitable for settlement by an agricultural people; for the region of the Jeddito Valley was then almost a desert, and the valleys and mesas were covered with moving dunes. In Jeddito time, the region was probably much more favorable than today, unless the climate was too cold. At this time, however, there is no record of any occupation, although it may be that in the future the remains of some early cultures will be found in the Jeddito formation.

## IMPACT OF ENVIRONMENTAL CHANGE ON PUEBLO HISTORY

### General Statement

The Hopi and other Pueblo peoples are closely dependent on their environment. They are a sedentary people subsisting mainly on agricultural produce whose abundance is directly associated with climatic and other physical conditions. The factor of physical environment is too often minimized or ignored in discussions of distribution and history of primitive peoples. It is well known that throughout the Plateau Country numerous ruins and works of the agricultural Pueblo testify to the former presence of a large population in regions which can now scarcely support a widely scattered and sparse semi-nomadic population of Navahos, Apaches and Paiutes. This modern sparse population is often forced to move from place to place because of local droughts, which cause the drying up of springs.

It is assumed by many that the introduction of commercial live stock by the white man has resulted in the destruction of the vegetative cover over large areas and is the sole cause for the ruination of a once verdant land. It is often assumed that before this time the climate has never changed and the arroyos have never cut down. Pueblo history is often explained without any consideration of the effect of physical environment.

Arroyos shift their courses, and change their gradients. The plant cover changes in response to climatic or ecological changes. Springs break out or dry up depending on the condition of their intake areas above. The entire history of the environment is one of constant instability and change. The delicate relationship between Pueblo economy and agriculture, and environment, make it obvious that these changes must have had their effect on Pueblo history and cultural development.

Reading the numerous accounts of travels in the Southwest before the recent epicycle of erosion began, one may obtain an exaggerated picture of the former fertility of the region. The accounts invariably describe tall grass, cotton-wood trees, pools of water, swampy areas, and so forth, but always along water courses. The plateaus and mesas, and areas with low ground water table, were very little changed by the recent epicycle of erosion, and have been unfavorable for settlement for hundreds of years. The great changes have taken place only along the stream courses on lands making up a very minor proportion of the total. These lands might be described as oases, for they were the places where the inhabitants made their living, and near which the population centered. It is true that most of the stream valleys and flood plains have been dissected and changed, and that former lush mead-

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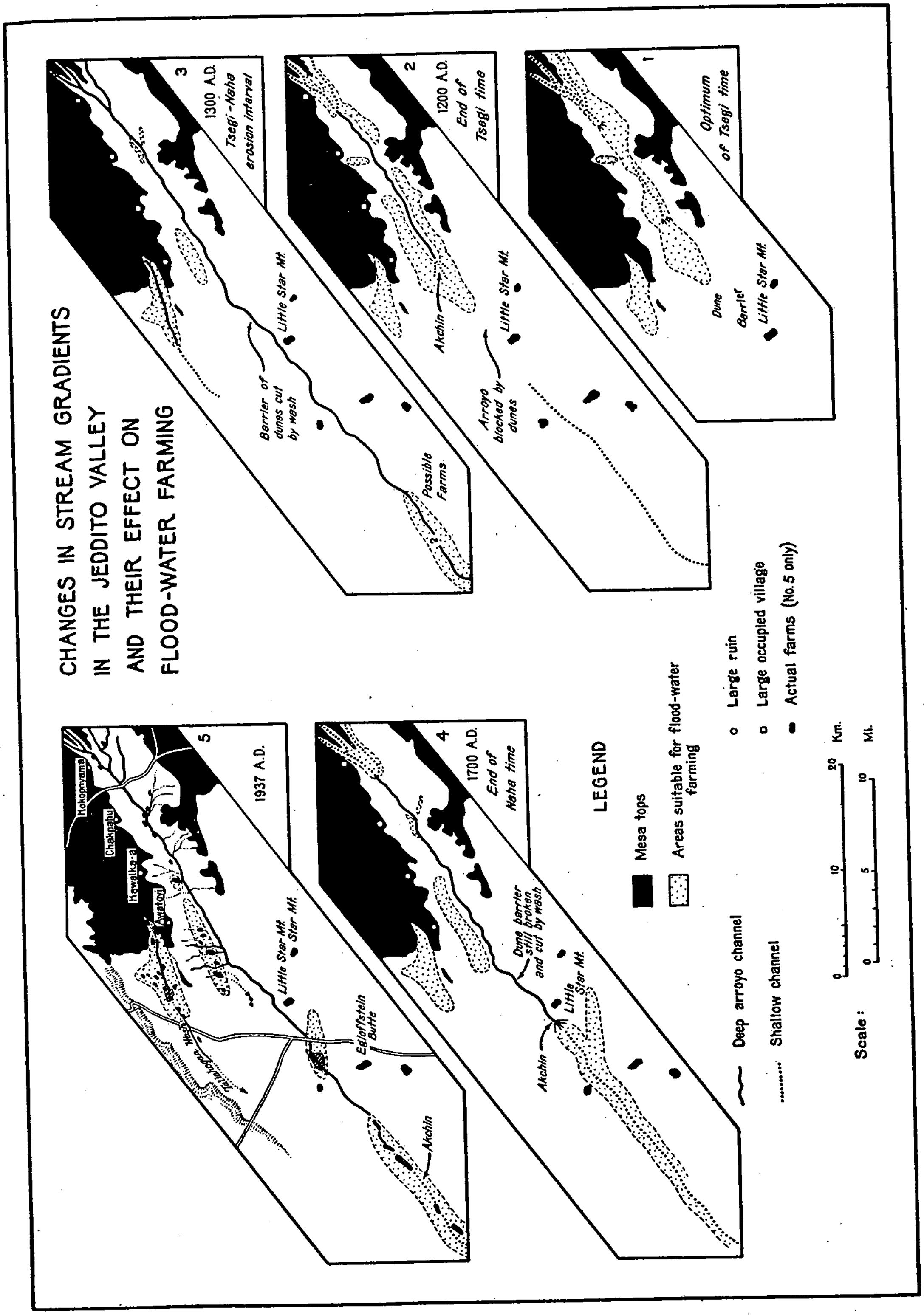


FIG. 53. History of the main stream of the Jeddito Wash, and its effect on flood-water farming. A series of hypothetical maps.

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